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Institute of Radio Engineers

Forthcoming Meetings

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September 22, 1931

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September 10, 1931

PROCEEDINGS OF The Institute of Radio Engineers

Volume 19

September, 1931

Number 9

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The Institute of Radio Engineers

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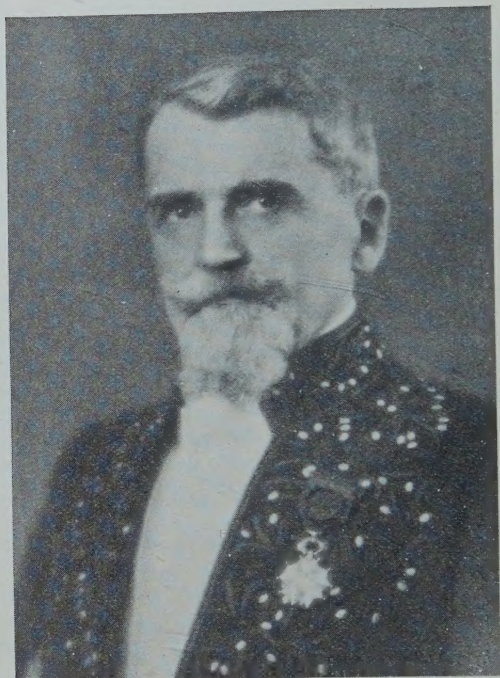
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G. A. FERRIÉ

Recipient of Institute Medal of Honor, 1931

In consideration of his pioneer work in the upbuilding of radio communication in France and in the world, his long continued leadership in the communication field, and his outstanding contributions to the organization of international cooperation in radio, the Medal of Honor of the Institute of Radio Engineers for 1931 was awarded to General Ferrié.

General Ferrié was born on November 19, 1868, at St. Michel, (Savoy), France. After being graduated from Polytechnical School in 1891, he became an officer in the Engineers Corps of the French Army.

He was made a General in 1919 and has continued in the service, being exempted from the restrictions of the age limit ruling in accordance with a special law enacted in 1930.

He received an Honorary Doctor's degree from Oxford University in 1919 and has been a member of the Academy of Sciences since 1922.

He is president of the International Scientific Radio Union (U.R.S.I.), the International Commission on Longitudes by Radio, and Vice President of the International Board of Scientific Unions. He became a Fellow of the Institute of Radio Engineers in 1917.

Presentation of Medal to General Ferrié at Copenhagen

Following the action of the Board in voting the Institute's Medal of Honor this year to General Ferrié, advantage was taken of the presence of a number of Institute members at an international conference at Copenhagen, Denmark, to carry out the presentation of the Medal at an appropriate dinner in his honor.

The occasion which brought so many radio engineers together at Copenhagen was the second meeting of the International Technical Consulting Committee on Radio Communication (CCIR) held, starting the latter part of May, upon the invitation of the Danish Government. It will be recalled that the CCIR is the committee which was set up under the Washington Radio Convention of 1927 to study radio technical matters, particularly those looking toward the reduction of interference and the most advantageous technical use of radio waves, and to report their findings to the various administrations. There was also being held at Copenhagen, at the same time, a meeting of the Union Radio-Scientifique Internationale (URSI), an international organization concerned with the study of the more strictly scientific side of radio phenomena. General Ferrié was very prominent in both meetings, being head of the French Delegation to the CCIR, and President of the URSI, so that the presentation of the Institute's Medal of Honor to him at this time was particularly appropriate.

The dinner was given by the American members present at the Conference to their foreign colleagues in honor of General Ferrié. It was held on June 7, 1931, at Nimb's Restaurant, one of the excellent restaurants of the city so well known for its hospitality. The forty-four participants represented most of the Institute members in attendance at the conferences.

Colonel A. G. Lee, who was head of the British Delegation to the CCIR Conference and who, it will be remembered, was last year Vice President of the Institute, officiated. A résumé of General Ferrié's many contributions to radio development and a very simple and charming eulogy of the General himself were given by Professor P. O. Pedersen, of the Royal Polytechnic School. As was appropriate, the actual presentation of the Medal was made by one of the early presidents of the Institute and an outstanding radio pioneer of America, Dr. L. W. Austin. The response made by General Ferrié was so gracious and full of warm friendship as to have been understood even by those of the English-speaking members who are single-channelled linguistically. Fortunately, a number of the Institute members were accompanied to

Copenhagen by their wives, so that the occasion was completed by a goodly number of ladies, including, in fact, Madame Ferrié herself. Telegrams of congratulations to General Ferrié were received from Signor Marconi and from Count Arco.

The name of Pedersen will remind readers of his colleague, Poulsen, of Poulsen arc fame, and it is with pleasure that we note the presence at the dinner of Dr. Poulsen. Thus, the occasion was honored by the presence of the two outstanding radio pioneers of Denmark. And, in the same connection, note should be made of the presence of another outstanding Danish communications engineer, Mr. K. Christiansen, Chief Engineer of the Danish Posts and Telegraphs, who was the president of the CCIR conference itself.

Bound Volumes

The twelve issues of the PROCEEDINGS published during 1930 are now available in blue buckram binding to members of the Institute at nine dollars and fifty cents (\$9.50) per volume. The price to nonmembers of the Institute is twelve (\$12.00) dollars per volume.

Radio Transmission of Standard Frequency, August and September, 1931

The Bureau of Standards announces a new schedule of radio transmissions of standard frequencies. This service may be used by broadcast and other stations in adjusting their transmitters to exact frequency, and by the public in calibrating frequency standards and transmitting and receiving apparatus. The signals are transmitted from the Bureau's station WWV, Washington, D. C. They can be heard and utilized by stations equipped for continuous-wave reception at distances up to about 1000 miles from Washington, and some of them at all points in the United States. The time schedules are different from those used in transmissions prior to this July.

There are two classes of transmissions provided: one, transmission of the highest accuracy at 5000 kc for two hours afternoon and two hours evening on three Tuesdays in each month; the other, transmissions of a number of frequencies in two-hour periods in the afternoon and evening, one Tuesday a month. The transmissions are by continuous-wave radiotelegraphy. The 5000-kc transmissions consists mainly of a continuous cw transmission, giving a continuous whistle in the receiving phones. The first five minutes of this transmission consist of the general call (CQ de WWV) and announcement of the frequency. The

frequency and the call letters of the station (WWV) are given every ten minutes thereafter. The transmissions of the other type are also by continuous-wave radiotelegraphy. A complete frequency transmission includes a "general call," "standard frequency signal," and "announcements." The general call is given at the beginning of each 18-minute period and continues for about two minutes. This includes a statement of the frequency. The Standard frequency signal is a series of very long dashes with the call letters (WWV) intervening; this signal continues for about 8 minutes. The announcements follow, and contain a statement of the frequency being transmitted and of the next frequency to be transmitted. There is then a 6-minute interval while the transmitting set is adjusted for the next frequency.

5000-Kilocycle Transmissions
2:00 to 4:00 P.M., and 10:00 P.M. to 12:00 Midnight, Eastern Standard Time

July	August	September
14	11	8
21	18	15
28	25	22
		29

Multifrequency Transmissions

Eastern Standard Time		Frequencies in Kilocycles		
		July 7	August 4	September 1
2:00 P.M.	10:00 P.M.	1600	3600	6400
2:18	10:18	1800	4000	7000
2:36	10:36	2000	4400	7600
2:54	10:54	2400	4800	8200
3:12	11:12	2800	5200	8800
3:30	11:30	3200	5600	9400
3:48	11:48	3600	6400	10000

Information on how to receive and utilize the signals is given in Bureau of Standards Letter Circular No. 280, which may be obtained by applying to the Bureau of Standards, Washington, D. C. Even though only a few frequencies are received (or even only a single one), persons can obtain as complete a frequency meter calibration as desired by the methods of generator harmonics.

The 5000-kc transmissions are from a transmitter of 1 kilowatt power; they occur every Tuesday except the first in each month. The other transmissions are from a transmitter of 1/2 kilowatt power; they are given on the first Tuesday of every month both afternoon and evening.

The frequencies in the 5000-kilocycle transmissions are piezo controlled, and are accurate to much better than a part in a million. The frequencies in the multifrequency transmissions are manually controlled, and are accurate to a part in a hundred thousand.

Since the start of the 5000-kc transmissions the Bureau of Standards has been receiving reports regarding the reception of these transmissions and their use for frequency measurements from nearly all parts of the United States, including the Pacific coast and Alaska. The Bureau is desirous of receiving more reports on these transmissions, especially because radio transmission phenomena change with the season of the year. The data thus far obtained cover the first six months of 1931, and give information regarding approximate field intensity, fading, and the suitability of the transmissions for frequency measurements.

It is suggested that in reporting upon the field intensity of these transmissions, the following designations be used where field intensity measurement apparatus is not at hand: (1) hardly perceptible, unreadable; (2) weak, readable now and then; (3) fairly good, readable with difficulty; (4) good, readable; (5) very good, perfectly readable.

A statement as to whether fading is present or not is desired, and if so, its characteristics, such as whether slow or rapid, and time between peaks of signal intensity. Statements as to the type of receiving set used in reporting on the transmissions and the type of antenna used are likewise desired. The Bureau would also appreciate reports on the use of the transmissions for purposes of frequency measurement or control.

Reports on the reception of the transmissions should be addressed to Bureau of Standards, Washington, D. C.

Institute Meetings

LOS ANGELES SECTION

The June meeting of the Los Angeles Section was held on the 23rd at the Mayfair Hotel in Los Angeles, Chairman T. E. Nikirk, presiding.

J. G. Alverson described a recording system employing a wire as the recording device. He reproduced a message from President Manson which was recorded in Rochester by Mr. Alverson. Dr. de Forest who was present responded to a request to record a short message of reply to Mr. Manson.

C. R. Daily of the Electrical Research Products, Inc., then presented a paper on the electrical and mechanical construction of the carbon, condenser, and moving-coil microphones. The description and comparison of these several types of microphones were well illustrated with slides. A standard condenser microphone and one of the new

moving-coil transmitters were on display so that a comparison of size and weight could be readily obtained.

The general discussion which followed the paper was entered into by several of the forty-five members and guests in attendance.

PHILADELPHIA SECTION

A meeting of the Philadelphia Section was held on June 17th at the Engineers Club. The paper of the evening "Producing Music from Colors" was presented by E. B. Patterson of the RCA Victor Company.

This paper was published in the August, 1931, issue of the PROCEEDINGS and will not be summarized here.

Following the presentation of the paper, the annual election of officers was held. G. W. Carpenter was elected chairman, R. S. Hayes, vice chairman, and George C. Blackwood was reelected secretary-treasurer.

The vice chairman presented the financial report of the secretary and also the report of the auditing committee. These were accepted unanimously.

The meeting was attended by one hundred and twenty members and guests.

WASHINGTON SECTION

The May 14 meeting of the Washington Section was held at the Continental Hotel and presided over by John B. Brady.

The paper of the evening was on "Improvements for Broadcasting" and was presented by T. A. M. Craven, formerly Lieutenant Commander of the U. S. Navy and now a broadcast consulting engineer.

The paper was illustrated with a large number of colored charts, diagrams, and curves and the underlying ideas were based on discussions with senators, congressmen, educators, radio engineers, broadcasters, and laymen for the past two years. The proposed plan is evolutionary rather than revolutionary and involves the following:

Five zones based on scientific principles: the first zone including New England, New York and Pennsylvania; second, the present third zone and all southern states east of the Mississippi; third, the states east of the Mississippi and north of the Ohio; fourth, all states between these and the present fifth zone; fifth, same as the present fifth zone. This distribution would give better contours to the zones, better relation between population and area and more satisfactory political division; for example, (1) includes New England, (2) the south, (3) Chicago and the railway group, (4) the community interests of the middle west, and (5) the far west. These zones also conform more nearly to the standard time zones. The zones would be subdivided into states and counties

and the stations therein should supply service rather than freedom from interference.

Instead of the present system of allocation Congress should pass laws making a system of evaluation based on three factors of (1) frequency, (2) square root of power, (3) hours of service. The range of frequencies should include the present and be extended to 530 kilocycles.

The administration should be chosen from all North American Nations, Canada, Mexico, and Cuba as well as the United States and should be based on international law.

The block system of allocation of frequencies should be used, having high power at the lower end of the spectrum, medium power in the middle section, and low power at the high end, giving greater flexibility.

The station management should improve its output in view of modern engineering and should have precise frequency control, high percentage of modulation and should suppress the sky wave by proper antenna systems.

Messrs. Burgess, Davis, Greaves, Robinson, and Smith of the thirty-six members and guests in attendance took part in the discussion which followed the paper. Nineteen were present at the informal dinner which preceded the meeting.

ROCHESTER FALL MEETING

As in the past two years, there will be a fall meeting of the Institute sponsored by the Rochester Section which will be held this year on November 9 and 10. An excellent program is being arranged for the two-day meeting and further details of it will be published in the October issue of the PROCEEDINGS.



PART II
TECHNICAL PAPERS

RADIO TRACKING OF METEOROLOGICAL BALLOONS*

By

W. R. BLAIR¹ AND H. M. LEWIS²

(¹Signal Corps Laboratories, Fort Monmouth, N. J.; ²Hazeltine Corporation, Bayside, N. Y.)

Summary—There is a need for upper air meteorological observation at night as well as in the daytime, in cloudy and in foggy weather as well as in clear. This need has given rise to a number of interesting methods of obtaining these data, among them radio tracking of meteorological balloons. A free balloon moves in the air current prevailing at the level it occupies. A small rubber balloon, six inches or less in diameter, when inflated with hydrogen to a given excess lift will rise at a given ascensional rate to great heights. Successive determinations of the position of one of these pilot balloons provides ready means for computing the mean direction and speed of the wind in the layer of air through which the balloon has risen during the interval between determinations of position. On clear days these balloons have been followed by visual methods to heights of 20 miles.

This paper deals with a radio method of determining successive balloon positions. A light transmitter, weighing about a pound, is carried up by the balloon at a known ascensional rate. Loop receivers are employed in ranging for this transmitter. The whole project involves the determination of air temperature aloft as well as air movement but the work on it so far has been limited to the development of equipment needed for the observation of wind, direction, and speed. Positions are usually determined at minute intervals. Tables and equipment employed in the reduction of data are made to fit this interval.

UNDER military as well as under civil conditions it is often desirable to obtain meteorological observations over terrain which is at times inaccessible or not readily accessible. Among such places may be mentioned the upper air, mountain tops, and places rendered inaccessible for the time because of military operation. Such meteorological data are often very desirable from the point of view of the forecaster and prove both directly and indirectly useful to commerce and industry. In addition to these uses, such data are of value to armies in the field in connection with their plans of maneuver and in the operation of such arms as Aircraft, Artillery, Sound Ranging, and Chemical Warfare.

Air pressure, temperature, humidity, movement, including direction and speed, and transparency are elements regularly observed. These, together with observations of clouds, including cloud height; thickness of cloud layer, as well as cloud type and amount; precipitation, including type, amount, and duration; fog; amount and character

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of sunshine and other elements are of direct, current interest to many commercial, industrial, and business operations, as well as to most military operations. These data from a considerable expanse of territory form the basis of weather forecasting. When compiled and tabulated, they constitute records from which climatic characteristics of different localities in the area covered may readily be obtained. These climatic characteristics are of the utmost value in connection with installations of any sort, either civil or military, and in making plans for operations. Observations of these meteorological elements on the earth's surface are usually easily made. Their observation in the upper air, especially at night or under cloudy or foggy conditions; also their observation in inaccessible places on the earth's surface present a separate and quite different problem.

Upper air meteorological observations are ordinarily limited to observations of air movement only, although meteorographs recording pressure temperature and humidity have been carried to heights of twenty miles or more by means of sounding balloons. When observations of wind direction and speed only are being made in the upper air, the method is to release a small rubber balloon and follow it by means of one or more theodolites. It has been found that the ascensional rates of these free rubber balloons can be quite accurately determined as a function of the weight, dimensions, and free lift of the balloon. Knowing the ascensional rate of the balloon, it is only necessary to observe its azimuth and elevation in order to determine its position at successive intervals of time. The interval usually employed is one minute. When these successive positions have been determined and plotted, it is a simple matter to read off wind direction and speed by means of scales suitably calibrated for the purpose. If observations independent of ascensional rate are desired, two theodolites and a base line are needed. For night observations the balloon is rendered visible by attaching to it a small paper lantern in which a candle is used as the source of illumination. This candle lantern can be kept on the cross hairs of the telescope and successive readings of azimuth and elevation obtained by means of the balloon theodolite just as in day observation. It is evident that this visual method of observing wind direction and speed aloft fails when fog, cloud, or other conditions of poor visibility prevail.

A number of special methods have been devised for making upper air observations in cloudy and foggy conditions. Two of these may be mentioned as illustrative of the more practicable of these methods. In point of time the first of these two methods consists in attaching a small bomb with time fuse to the balloon and sound ranging for the explosion

of the bomb. During the War an installation for making observations by this method was in operation in the First Army area. This installation consisted of a network of seven microphones arranged on two lines at right angles to each other, and a central station into which the microphones were wired for the purpose of recording the sounds they picked up. All microphones recorded on the same strip of smoked paper. The results were reduced and balloon positions determined at this central station. In operating the installation, the balloon would be inflated, its ascensional rate roughly estimated, and a bomb with a suitable time fuse attached. The balloon would then be carried to such distance to the windward and released that by the time it had arrived approximately above the network of microphones the bomb would be detonated. Using this determination of wind direction and speed, a second balloon would be prepared and released at such a point that its bomb would be detonated at a higher level and approximately over the network of microphones, etc. The method is quite tedious and expensive because of the complicated computations involved and the considerable number of balloons employed. Three or four hours would be required to make an observation to the height of the trajectory ordinarily employed by the 75-mm. guns. A period of three or four hours often includes considerable changes in wind direction and speed. Another rather serious objection, especially for peace time use, is that a faulty balloon instead of carrying its bomb into the upper air may develop a leak and deposit the bomb where it will do more or less damage. It happened overseas, for example, that one of these bombs exploded on a roof. Another exploded in an automobile damaging it very considerably. This same criticism applies to some extent to the use of the lantern for night observations. A faulty balloon might lower the lantern into inflammable material causing fire.

A second method of making observations of wind direction and speed aloft under conditions of poor visibility consisted in firing round balls in a vertical direction and noting the point at which they returned to earth. The wind direction and speed are then computed from their effect in deflecting the ball from its vertical course. In practice a series of shots are made using different charges so that the balls will successively reach higher and higher levels. This method appears to be feasible, but requires a good deal of computation. It was proposed and experimented with in England, but has not been widely employed.

While the need for some simpler method of making upper air observations, and in general meteorological observations in inaccessible places, was evident during the war and some thought had been given to the radio method, it was not practicable to start experimental work on

this method until the year 1923 and 1924. The initial work was done in the Signal Corps Laboratories at McCook Field and carried along to the point where, with a simple buzzer transmitter weighing just under a pound, signals were heard and a balloon tracked for twenty minutes. Since the balloon ascends 200 yards per minute, this flight furnished fairly reliable observations to a height of 4000 yards. The receiver equipment employed was a breadboard layout with improvised loop. From the observer's point of view, the results were only fairly good but indicated that the method was deserving of further study and improvement. Some experimental work was also done with a view to having the transmitter indicate air temperature in addition to furnishing a radio signal for tracking purposes. While these experiments gave promise of success, the complications introduced into the transmitter led to the decision to limit the problem for the time to radio tracking. Now that the radio tracking problem has been fairly satisfactorily solved, the problem will be continued with a view to being able to determine temperatures aloft as well as balloon positions. This experimental work was interrupted by work in connection with the world flight. It was transferred from the Signal Corps Laboratories, McCook Field, to the Signal Corps Radio Laboratories at Fort Monmouth at the end of the year 1923 and 1924, but active work on the project was not taken up again until rather recently.

For the engineer, two problems are presented by the proposal to track meteorological balloons by radio. First, the development of an inexpensive transmitter weighing as little as possible, and second, the development of a portable direction finding receiver of rugged reliable construction having a minimum number of operating controls. The apparatus developed approaches quite satisfactorily these requirements.

As to the transmitter, the aim was for a weight of one pound for the complete outfit including battery and antenna. A small transmitter employing a buzzer arranged to energize a spark gap was soon ruled out although various refinements such as small quenched gaps were tested. Although better than 50 ma of high-frequency current could be put into the antenna system by spark excitation the broadness of the resulting wave meant that this energy was distributed over a broad frequency spectrum and that actually at any frequency in this band to which the receiver was tuned, only a small amount of radiated energy was effective and the resulting signal was weak. The roughness of the note with spark transmission, the broadness of tuning and the uncertainty due to the fact that the buzzer vibrator might stick when adjustment was made for a maximum output, directed the development toward a vacuum tube transmitter. Here, however, the need of a

high voltage plate battery, which is both light and inexpensive, ruled out the simplest arrangement of a steady continuous wave signal.

The solution which was arrived at early in this development was found at once to be both effective and reliable and has been used since early in 1928 for a variety of tests in the development of the direction finding receivers, in testing their range and for the actual balloon tracking tests. It consists of a small flashlight $4\frac{1}{2}$ -volt battery which serves to heat the filament of a 199-type tube and simultaneously to energize the primary circuit of a buzzer transformer. The turn ratio of

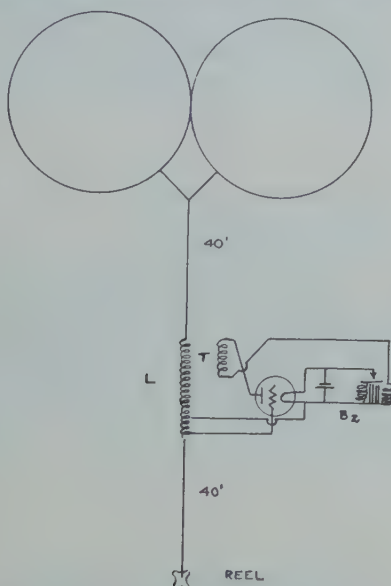


Fig. 1—BC-164 transmitter circuits.

the transformer is about 50/1 and its iron core is provided with an air gap to give leakage flux for operation of the vibrator or interrupter which is included in the primary circuit. The secondary voltage is, of course, intermittent at the rate of vibration of the interrupter and it is this voltage, or rather that part of it, which makes the plate positive during each cycle of the vibrator, which is applied as B voltage to the 199 tube.

The circuit is shown in Fig. 1, which also gives an idea of the manner in which the transmitter is carried by the balloons so that the supporting and trailing wires constitute an antenna and counterpoise. Perhaps it is better to say that they act as the two legs of a rather ideal dipole radiator and it is, of course, this ideal radiating system that

gives this transmitter its effectiveness with the small amount of energy supplied to it. The frequency or wavelength radiated depends on the length of the legs chosen in conjunction with the circuit inductance. The length of each of these legs has been arbitrarily chosen as 40 feet to set the wavelength near 125 meters, but this length is not critical and the legs may be shortened or lengthened as desired to set the frequency. In fact one leg may be omitted and the frequency, as determined by the capacity of a single wire to the set, is sufficient to maintain effective oscillations at what is then a much shorter wavelength.

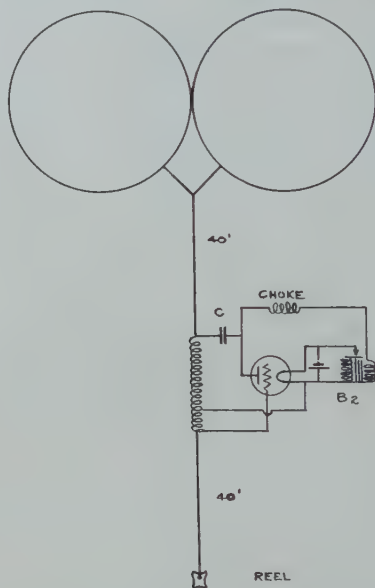


Fig. 2—BC-164 transmitter circuits.

The nature of the feed-back circuit needs no explanation as it is evident from the diagram. An alternate circuit arrangement which was used in some tests but which is more critical to change in the length of dipole legs is shown in Fig. 2, and being a fundamental type of oscillating circuit, also needs no description.

The small transmitter, which is now known as Signal Corps Type BC-164, is shown in Fig. 3 and a number of these transmitters as built at Fort Monmouth, together with the dummy antenna test stand, the $4\frac{1}{2}$ -volt flashlight battery and a reel upon which the two antenna legs are wound, are shown in Fig. 4. In Fig. 5 the transmitter is one wired as in circuit Fig. 2, and this view gives a somewhat clearer idea of the manner in which the battery is slipped into position between spring

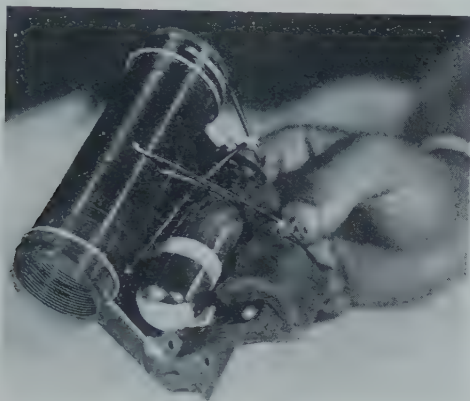


Fig. 3

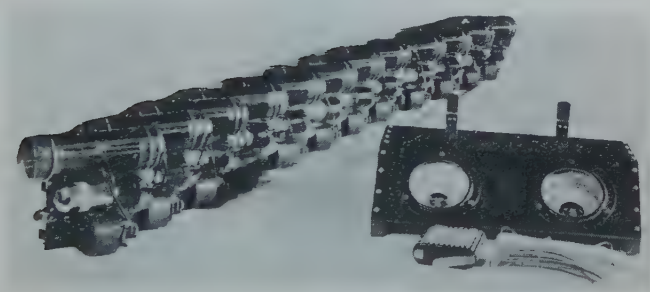


Fig. 4



Fig. 5

clips. Fig. 6 shows the transmitter in place on the test stand. The dummy antenna is simply a small 20- μmf capacity in series with the thermomilliammeter showing on the panel. In placing the transmitter on this test stand, with the battery in position, the other meter showing on the panel is cut into the circuit to indicate the d-c drain from the battery. The vibrator of the buzzer is then adjusted to give a tone of even and steady pitch and to assure that not over 200 ma are drawn from the battery. With such an adjustment, the high-frequency current through the dummy antenna should be from 25 to 35 ma. It may be noted that this is equivalent to the high-frequency current which the set would furnish if a plate battery of 120 volts were used in place of the buzzer transformer plate supply.



Fig. 6

The entire weight of the complete transmitter is $17\frac{1}{4}$ ounces. The instrument itself weighs 11 ounces, the battery $4\frac{1}{4}$ ounces, while the antenna legs and reel weigh the remaining 2 ounces. With the receiver to be described, signals from this transmitter, when it is suspended from a supporting wire between the antenna towers at Fort Monmouth, are readable at 11 miles, and directional reception accurate to less than one-half of a degree is had at a distance of 5 miles. Equally accurate directional reception obtains over the same and probably greater distances from these transmitters when they are carried aloft by balloons. The transmitter, when supplied with a fresh battery, will continuously transmit its modulated signal for at least one-half hour. Generally the signal continues for three or four hours uninterrupted except for an occasional shift in the tone of the buzzer. In cases where the battery happened to be a good one (i.e., one which did not rapidly polarize) the signal transmitted has been continuous for over seven

hours and has therefore permitted an entire day of testing with the direction finders at various distances from the signal.

Before a number of these transmitters were available so that they might be expended in actual tracking tests, it was necessary to get information on range, etc., by moving the receivers as mentioned. However, on one occasion through the courtesy of the Naval Station at Lakehurst, N.J., the transmitter was carried suspended from one of the smaller blimps, and at another time an army plane coöperated in flying the transmitter. From these tests, as well as the subsequent balloon ascensions, it appears that the distance at which the signal may be received is of the same order as indicated by the land tests.

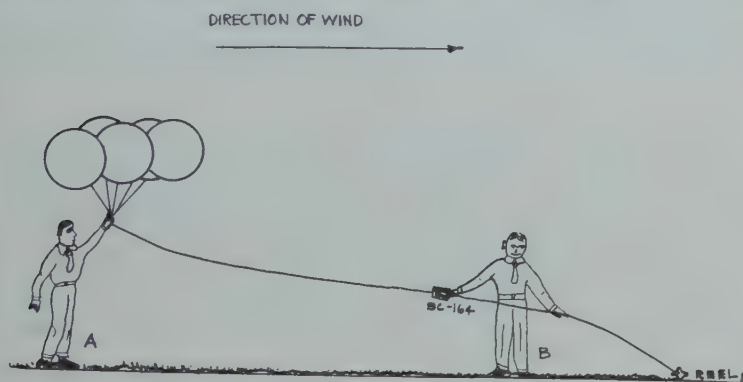


Fig. 7—Radio tracking of meteorological balloons. Releasing balloons with transmitter.

"A" moves rapidly towards "B" allowing wire to slide through his hand. On reaching "B" both men "let go."

In making actual balloon tests the transmitter is adjusted in the test stand, as described, immediately before releasing the balloons and is in fact operating on the test stand until the moment it is removed for attachment to the upper antenna leg which holds the balloons captive. Clusters of four and and of six balloons have been used. These are the standard 6-inch (uninflated) balloons used for theodolite work. A single large balloon may replace these clusters. In the first trials, the attempt was made to hold the balloons captive by a light insulating cord attached to the antenna reel and thus permit each direction finder to tune in and note that the signal tone was steady and of good volume before releasing them. Sudden wind gusts would then generally break the antenna wire and the balloons would be lost. The procedure illustrated in Fig. 7 was then successfully adopted. The man at A holds the balloons while the man at B, having tested the BC-164 transmitter,

attaches it between the two antenna legs; the lower leg lying extended on the ground. *A* then runs rapidly toward *B*, letting the antenna wire slide through his hands to allow the balloons to rise. On reaching *B* both men let go and the balloons carry the system aloft without difficulty. The signal from the transmitter is always loud and clear the instant the lower end of the antenna leaves the ground and is easily tuned in on the receivers.

The signal is a clear musical note apparently being that of a tone modulated continuous wave and the entire energy of the signal is in fact confined to a narrow frequency band. Of course no carrier wave exists in this system and heterodyne reception, which is resorted to by the operator after the balloons have traveled two to three miles and the signal has become weaker, results in giving a signal of a characteristic hissing sound which is readily recognizable from any other type of signal.

The direction finding receiver will be of interest to engineers in that it covers the band of frequencies immediately higher than the broadcast band, employs single control tuned radio amplification, and has controlled regeneration confined to the detector so that cw signals may be received. The direction finding input is of interest in that capacity neutralization is employed to eliminate the antenna effect and an aperiodic loop is used. The mechanical arrangement is such that the outfit is readily portable.

In arriving at the design of the direction finder to be described, a number of circuits were tried and existing direction finders were studied. Experiments toward a "maximum method" were not sufficiently promising in comparison with the "null" method to warrant an extended study at the time these receivers were developed in 1927-1928. Some consideration was given to the problem of a three-dimensional direction finder as this would permit direct determination of the angle of elevation of the balloons as is done with the visual theodolite method, and some experiments with a small dipole receiving antenna were conducted. It appears from theory that a combination loop and dipole rotatable about both a vertical and horizontal axis will give this desired characteristic. The capacities to ground of the dipole are, however, more difficult to correct than those of the loop, and to produce a combination loop and dipole in a single portable structure with their outputs properly adding in the receiver input appeared to involve a more extended investigation than could be justified. It was therefore decided to rely upon giving the balloons the proper inflation to determine elevation by their ascensional rate and see if we could build a simple direction finder that would suffice. The three-dimensional direction finder

is, however, a fascinating problem and its solution in a direct reading portable apparatus will undoubtedly be attempted since it would serve many military purposes as for example following aircraft.

As to the existing direction finders available at Fort Monmouth, they were not of a form suitable for field use and the reading of a single null point was not always reliable to indicate the correct bearing. A 180-degree rotation of the loop to give a check of the opposite null or zero was generally necessary so that an average of the two might be had. The reason for this appears to be chiefly due to direct pick-up of signal upon the set itself as well as to inaccurate elimination of antenna effect. Since the balloons are in motion and readings at regular intervals must be recorded, the delay such checking or averaging would require was not permissible. Since two receivers located at ends of a base line follow the moving signal, only direction and not sense is required and so the complication of providing this function was eliminated also.

A first model employed the superheterodyne circuit, and with it a variety of input circuits were tested. Two stages of tuned, single control radio-frequency amplification preceded the first detector, and in the development of this part of the receiver, sufficient amplification and selectivity were realized so that the receiver eventually became simply two stages of radio frequency, regenerative detector, and two audio stages. Throughout the work the simple idea was adhered to of eliminating all direct pick-up on the receiver and devising an effective compensator for antenna effect so that a single null reading would be accepted as reliable. Thus the operator was to turn but a single dial to bring in the signal. The regenerative knob was to be in the nature of a gain or volume control not affecting the tuning. With the signal tuned in, the operator need only to rotate the loop to observe the direction indicating zero and vary the compensator control slightly to sharpen the zero if necessary. The compensation control was to be eliminated if possible. The loop and compensator controls were to be entirely independent of tuning and free from any reaction on the receiver. The receiver as completed accomplishes quite well these requirements.

The development of an acceptable input circuit may be explained by reference to the series of diagrams of Fig. 8. It will be noted that these circuits all show an aperiodic loop or rather one that is tuned indirectly by the first tuned circuit of the receiver. One advantage of the aperiodic loop is freedom from capacity effects since the loop terminals are at relatively low potentials as compared with the similar terminals of a multiturn tuned loop. Perhaps it is clearer to say that the capacity of the loop to ground, to the set, or to the operator is in effect less dis-

turbing since the loop is indirectly tuned by a large capacity introduced by the tuned circuit to which it is coupled. This meant in practice that loop shielding was unnecessary. A still more important advantage of the aperiodic loop is that it permits single control tuning to be more easily realized and in the receiver as completed "plug-in coils" may be used to operate the receiver in a different frequency band without substituting another loop.

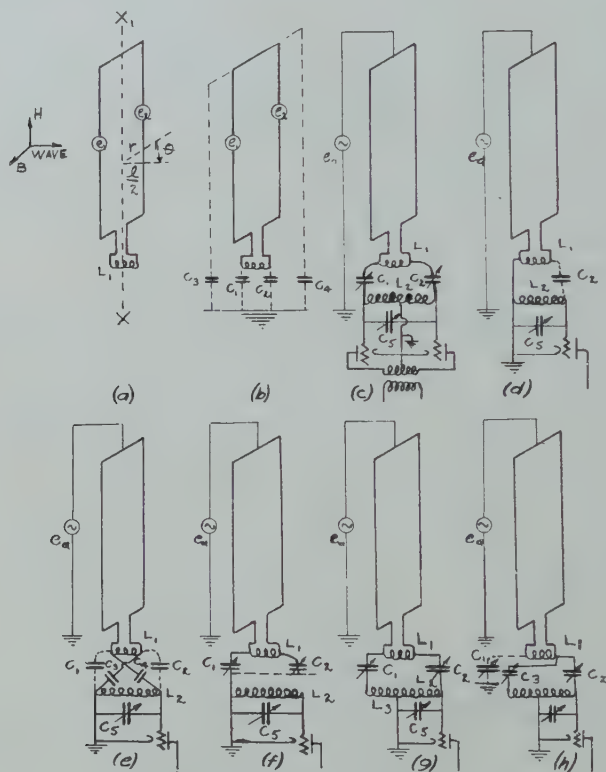


Fig. 8—Loop input circuits.

Starting then with Fig. 8(a) the loop and output inductance L_1 is represented as isolated in space and rotatable about the vertical axis $x x_1$. The wave passing this loop will be considered to be of the conventional type, one having the electric vector vertically polarized and coming from a single direction as indicated in the diagram. The well-known fact is that in such a symmetrical circuit, the resulting voltage developed across L_1 is proportional to the cosine θ , where θ is the angle made by the plane of the loop with the direction of the approaching wave. This is merely stating that the loop will give the well-known

"figure-8" characteristic when rotated, and the received voltage plotted as a polar diagram. A convenient picture is to consider that the approaching wave would induce a voltage $e = E \sin \omega t$ in a conductor of the same height as the loop located at its axis, and therefore does induce voltages e_1 and e_2 in two sides of the loop as indicated in the diagram. It is then shown that

$$e_1 - e_2 = \frac{4\pi r}{\lambda} \cos \theta E \cos \omega t.$$

This is the voltage across L_1 . It varies as the cosine of the angle as the loop is rotated and its phase is different by 90 degrees from that which would have been produced in an antenna located at the axis.

The result of having our loop brought close to ground is that capacity of the entire structure to ground results and this condition is represented in Fig. 8(b) by assuming the loop still to be symmetrically positioned from ground and representing the resulting distributed capacity by four capacities C_1 , C_2 , C_3 , and C_4 . Each of the generators e_1 and e_2 now supplies a complicated net and it is evident that the voltage developed across L_1 will not vary as cosine θ unless the capacity paths C_1 , C_3 and C_2 , C_4 are equalized so that ground, the center of L_1 and the top center of the loop are conjugate points in the system. A lack of such symmetry gives what is termed the antenna effect because the resulting polar characteristic is equivalent to that of a perfectly balanced loop plus an antenna. It follows then that when the system is balanced symmetrically so that antenna effect is absent we may connect a source of high-frequency voltage, to which the receiver is tuned, between the top center point of the loop and ground without introducing any across the coil L_1 . Or, again, considering the coil L_1 as being inside the receiver and the loop absent, a test of symmetry within the receiver is to connect the terminals of L_1 together and to a terminal of a signal generator, the other terminal of the signal generator being grounded actually or connected to the common ground of the receiver, and discover that zero signal results. These two tests were, therefore, made standard in determining the merits of compensating circuits. The shielded signal generator was generally connected as indicated by e_a in the diagram, the ground terminal connecting to the negative filament of the receiver and the high potential terminal connecting to the top center of the loop by a wire symmetrically placed relative to the sides of the loop. Adjustment of the compensator was then quite similar to the balancing of an inductance bridge or the neutralizing of a vacuum tube and determined by obtaining a "null" signal in the telephones.

Thus in Fig. 8(c) there is shown a push-pull input circuit which was one of the types used as it is inherently symmetrical. Here the signal generator e_a is connected as described. With similar tubes and precautions taken in the design, C_1 equals C_2 for balance or compensation of antenna effect. Lack of symmetry can be remedied by varying the capacity of either of these capacities which are therefore made actual physical condensers. When a balance is thus obtained with the signal generator the system is also found to be balanced for actual signals received. As the loop is rotated, however, its capacity to ground will vary, since the capacity of one-half of it to ground may differ from that of the other half to ground in one position and reversing or rotating the loop 180 degrees reverses these capacity values. An electrostatic shield, grounded and rotatable with the loop almost completely eliminates this effect and is very desirable for the multiturn tuned loop. However, this addition of shielding is of little value with the aperiodic loop since such capacity effects are of small importance as previously explained and its added weight is objectionable in a portable set. In practice, therefore, one of the condensers, C_1 or C_2 , is brought out to the panel as a compensation control. The coupling of L_1 with L_2 is preferably close so that the loop is indirectly tuned by C_5 but this is not necessarily so, as the coupling may be entirely capacitive through the condensers C_1 and C_2 .

In the push-pull input circuit of Fig. 8(c) the tuning condenser necessarily has both rotor and stator plates above ground and this is objectionable from the point of view of single control where a gang condenser of the usual type is economically desirable. To connect the loop as in Fig. 8(d) would obviously make the system extremely unsymmetrical as the voltage in one side of the loop has a direct path to ground while that in the other side has the capacity C_2 and inductance L_2 as an additional path to ground.

In Fig. 8(e) the loop is shown coupled by L_1 to L_2 , and the capacity coupling between the coils is represented by the small capacities C_1 , C_2 , C_3 , and C_4 . It is impossible, even by making some of these capacities small adjustable condensers, to compensate this circuit since currents through C_1 and C_3 produce no effect upon the grid of the tube while capacities C_2 and C_4 complete the circuit of the signal generator e_a to ground through the inductance L_2 and each produces a voltage between grid and filament. Furthermore the voltages so produced are in phase and add so that no relative adjustment of these capacities will avail in giving compensation.

If then a single tube input is to be had, we must resort to one of the three following types of circuits which either eliminates the capacity

coupling between the windings leaving only magnetic coupling, or neutralizes its effect in so far as the generator e_a is concerned. Hence, in Fig. 8(f) the elimination of antenna effect is shown as accomplished by the use of an electrostatic shielding screen. The screen itself is at ground potential and so prevents capacity paths for currents from the generator e_a being completed to ground via the inductance L_1 . The voltage induced in L_2 is therefore by magnetic coupling entirely. But to insure the cosine law as the loop is rotated it is important that the conditions outlined for Figs. 8(a) and 8(b) shall obtain and hence the capacities C_1 and C_2 to ground must still be equalized so that ground, the center of coil L_1 , and the top center of the loop are conjugate points. Thus with the electrostatic shield it is desirable

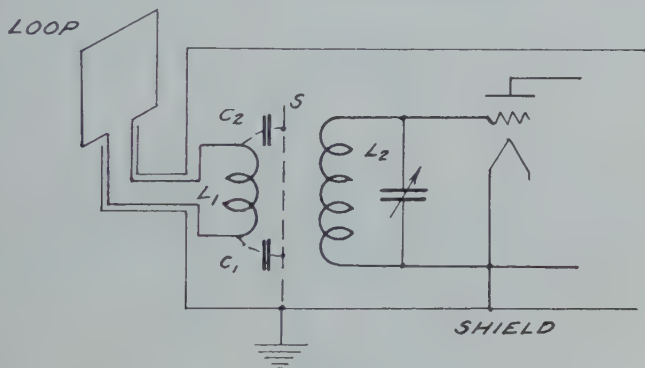


Fig. 9

to use two small physical condensers for C_1 and C_2 giving one some arbitrary value and bringing the other out on the panel as a compensating control. This arrangement proved in practice to be an excellent direction finding input, but was not used because the losses in the screen employed decreased the received signal too much. A proper screen would make this input circuit entirely acceptable and since these early tests such a screen (made up of parallel strands of fine wire formed by winding the wire on a tubular form, fixing the winding with cellulose, and cutting it to form a flat surface) has been found to give practically no loss. The parallel wires are soldered at one end and grounded, the other ends being open to form a grid. Such a shield may be effectively used between the windings of high-frequency transformers of the usual cylindrical form. The actual arrangement of such an input circuit is shown in Fig. 9.

In Fig. 8(g) a neutralizing winding L_3 is effective in giving accurate compensation. Practically unity coupling is sought between L_2 and L_3 ,

and close coupling between L_1 and L_2 is utilized to give maximum transfer of energy from the loop to the grid circuit and to allow the loop to be aperiodic or in fact tuned by the circuit L_2C_5 . The capacities C_1 and C_2 are made to be physical condensers and are respectively a small neutralizing condenser ($50\ \mu\mu\text{f}$ maximum) which is set at any arbitrary value and a small variable condenser appearing as a control knob on the panel of the receiver. The voltage produced by the current due to e_a flowing to ground via C_2L_2 is neutralized by the effect of current in the same time phase flowing to ground via C_1L_3 . The unity coupling between L_2 and L_3 assures that the flux set up by each of these currents shall produce a resultant zero flux as far as the generator

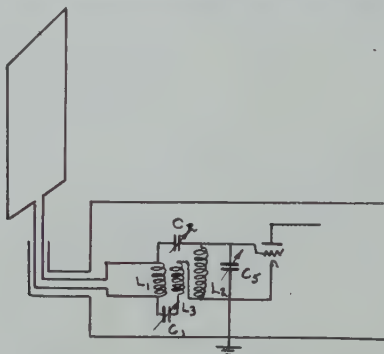


Fig. 10—Loop input circuit.

e_a is concerned. As to the desired signaling voltages, when in practice the loop is not set for zero signal from an incoming wave, these capacities C_1 and C_2 aid and it is possible to use no magnetic coupling between L_1 and L_2 leaving the circuit as a capacity coupled system. The operation of this circuit is both simple and effective and holds without readjustment over the wide frequency band of the receiver since it is independent of frequency. Only slight readjustment of the compensating condenser C_1 is necessary on rotating the loop 180 degrees. The actual arrangement of parts is shown in Fig. 10.

Fig. 8(h) is the circuit finally used in the finished apparatus and differs only slightly from Fig. 8(g) since it employs the neutralizing winding L_3 . The functions of neutralizing the capacity in its effect upon the grid circuit and of preserving the symmetry of the loop system are, however, separated in this circuit so that the in-phase voltages are applied to L_2 and L_3 thru condensers C_2 and C_3 both condensers being supplied from the same terminal of L_1 . The coil L_1 is equalized in its capacity to ground (so that currents in L_1 obey the cosine law) by giving C_1 its proper value. This capacity C_1 should, in theory be physically present

as a definite condenser adjusted accurately. In practice, however, it is present only as the inherent capacity of L_1 to ground, and C_2 and C_3 being relatively adjustable, correct for any unbalance. C_2 is in practice left variable as a compensator control on the panel of the receiver and its operation is entirely effective and satisfactory. The circuit is redrawn in more accurate form in Figure 11.

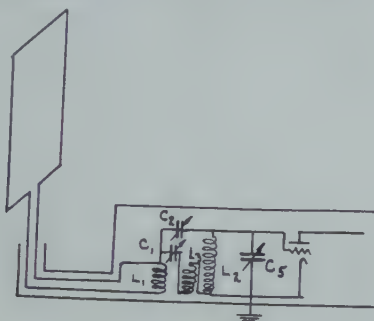


Fig. 11—Loop input circuit.

It will be clear from the foregoing that two conditions of balance must be maintained to eliminate the effect of e_a . First, the symmetry of the loop system, including L_1 , in its capacity paths to ground must be maintained. Second, the equalized capacity paths to ground, necessary

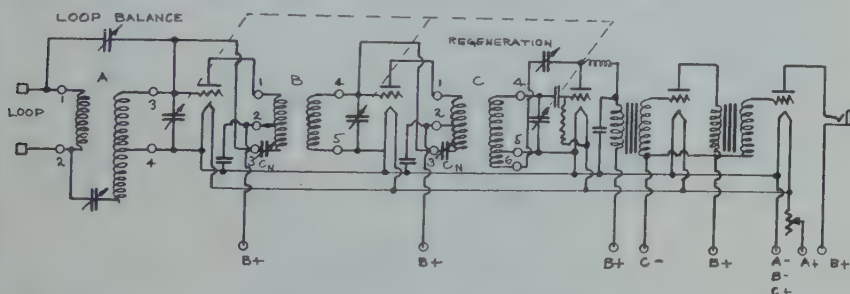


Fig. 12—Meteorological receiver circuit first shielded model. A, B, and C are plug coils carrying neutralizing condensers C_N .

to preserve the first condition, must not include the grid circuit in a way to produce antenna effect voltages. Thus, of the circuits shown, Fig. 8(c), 8(f), 8(g), 8(h) are acceptable circuits and the last three are preferred since they are effective input circuits with a single vacuum tube.

The Fig. 8(g) input circuit was the first one used in practice as shown in Fig. 12. In Fig. 13 is shown the final circuit used; the difference being chiefly in the use of the Fig. 8(h) circuit for the input and in the

additional choke coils and by-pass condensers as will be explained. Figs. 14 to 20 show the receiver as developed and give an idea of the

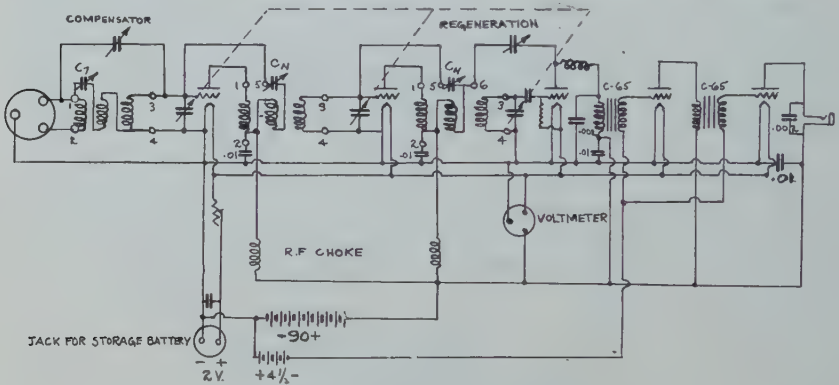


Fig. 13—Circuit for SCR-170 meteorological receiver.

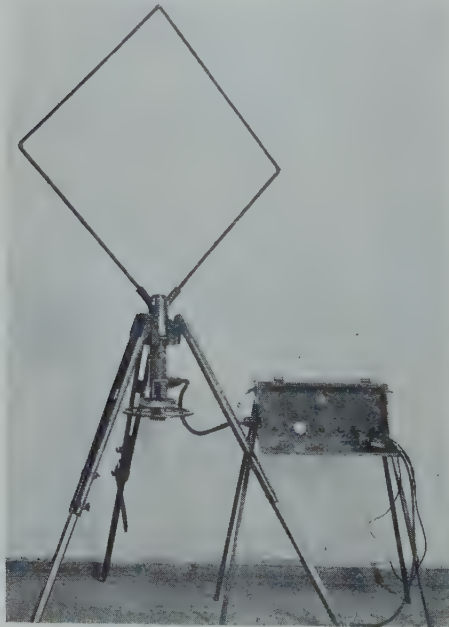


Fig. 14

shielding employed. They also show its portable nature and the manner in which it is packed. This receiver is known as the Signal Corps SCR-170.

Referring now to Figs. 13 and 14 to 20, the loop plugs into the jack of the receiver by means of a flexible shielded cord. The metal parts of the loop support are thus grounded to the frame of the metal chassis which fits into the copper-lined cabinet. Each r-f transformer coil is of the plug-in type, so that new coils may be provided for other frequency bands, to utilize the apparatus for general direction finding purposes. Each coil is encased in a copper can, primarily to give magnetic shield-

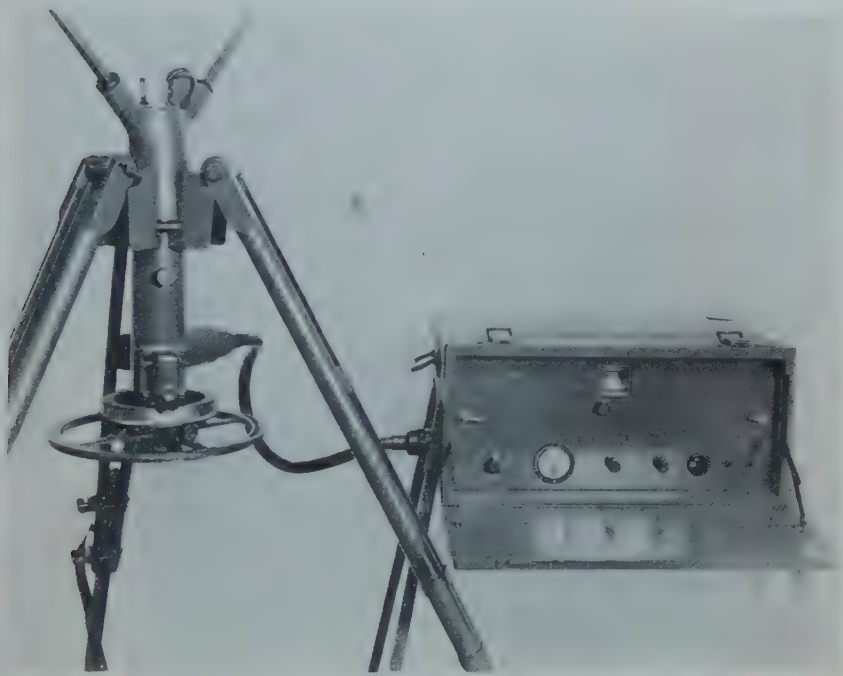


Fig. 15

ing. The gang condenser has three units each of maximum capacity $350\ \mu\text{mf}$. The frequency band covered is 1700 to 3300 kc. The neutralizing condensers are an integral part of the plug-in coils *B* and *C*, while coil *A* carries the condenser C_1 necessary to the compensation system shown in Fig. 11 and Fig. 8(h). This is desirable for plug-in coil systems, since it simplifies the design of additional sets of coils and assures neutralization when a set of coils is plugged in. The shielding shown was adopted to prevent all direct pick-up of signal on the receiver and to prevent reactions between the loop and the receiver. For this reason the B batteries are placed inside the shielded set box in a well, formed as part of the receiver subpanel. An extra $2000\text{-}\mu\text{mf}$ condenser shunts the telephones directly at the jack, and a $1/4\text{-}\mu\text{f}$ condenser from the

low side of the jack leads directly to ground. This effectively reduces "pick-up" on the headphone cords. The A battery is outside the set. It was found necessary to place a $1/4\text{-}\mu\text{f}$ by-pass across the A battery jack and ground the negative filament at this point to the metal chassis to eliminate pick-up of signal at this point. Experiments show that if the negative filament system were grounded to the chassis at this one point alone, and no other grounds of the circuit to the chassis are made, many reactions are avoided and greater stability of the receiver is had.



Fig. 16

It was not feasible to follow this practice on the apparatus built but it is believed that on future models it should be done. For example, the gang condenser grounds to the metal chassis at three points and the drum dial provides an additional connection of the circuit to the chassis. Elimination of these grounds should prevent any current flow through the chassis.

The r-f transformer coils are wound by having the primary and neutralizing windings similar in a double thread cut in the bakelite form. The secondary is on celluloid wound directly over the primary. This procedure was adopted when it was found that close coupling the primary and secondary windings, poled so that capacity coupling between windings aided the magnetic coupling, gave good amplification gains

at these short wavelengths. Because of this poling of the windings the extra neutralizing winding is required. Since the loop is not directly tuned but closely coupled by L_1 to L_2 it acts upon L_2 as a short-circuited secondary winding to reduce its inductance. For this reason a few turns



Fig. 17

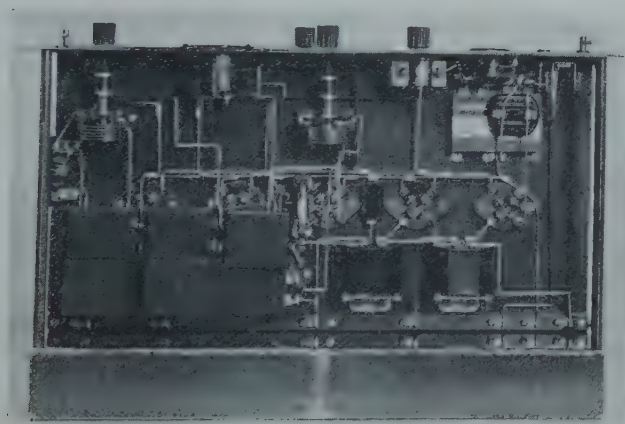


Fig. 18

are added to L_2 and its inductance measured, with the loop connected in circuit, to match the secondary inductances of the other r-f stages. This fact is of importance in securing single control tuning with this aperiodic loop.

During the development of the receiver screen-grid tubes were tried. It appeared that three-element tubes using capacity neutralization

better isolated each stage than did the use of screen-grid tubes. It should be remembered that regeneration of the detector is employed and the tests of neutralization required that the tuning of the r-f stages or the adjustment of the compensator should not affect the pitch of

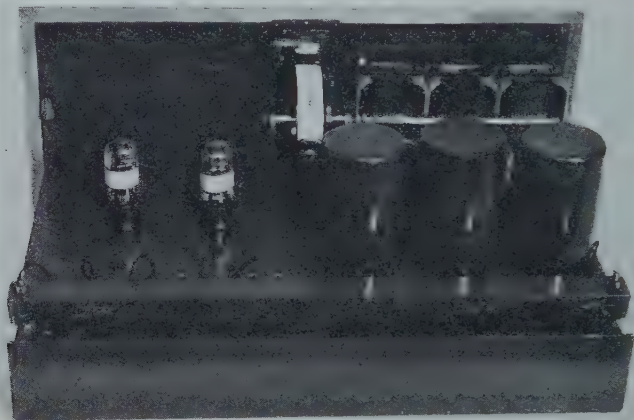


Fig. 19

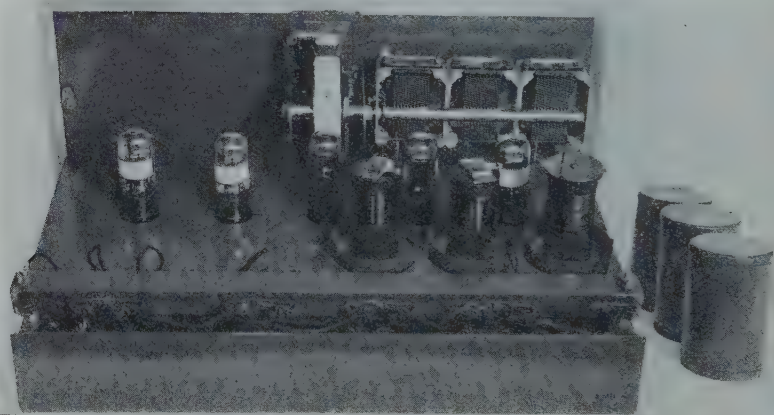


Fig. 20

the beat note when the detector was oscillating and thus heterodyning an incoming carrier wave to produce a low note near zero beat.

The neutralization achieved on the first model which used UX-201-A tubes satisfied the above requirement. The following models use the new UX-864 tube which has been adopted in several other Signal

Corps sets because it is essentially a dry battery tube and is quite non-microphonic. On these models there is still an appreciable reaction of the compensator on the beat note when receiving cw signals. Since the BC-164 gives a modulated tone and when heterodyned gives a hissing sound because of the absence of a continuous carrier wave, this reaction was not corrected as it did not prevent the proper functioning of the direction finder for tracking balloons. It should, however, be rectified in future models and it is for that reason that the suggestion was made of eliminating unnecessary grounding of the circuit to the chassis.



Fig. 21

The regeneration control utilizes a neutralizing winding of the transformer *C* as a feed-back winding. This particular form of regeneration control appeared to be most desirable in accomplishing the desired single control. The close coupling of the feed-back neutralizing winding gives regeneration which will hold close to its maximum setting as the receiver is tuned over its rather wide frequency band. If regeneration is set at a maximum at the highest frequency, it needs only the slightest advance to bring it to a maximum at the lowest frequency. Also, with this form of regeneration, the three tuned circuits could be brought into resonance at the highest frequency of the range by trim-

ming capacities (which are on each condenser unit, but not shown in the circuit) and the circuits would stay in resonance over the frequency band so that single dial control is possible. In aligning the circuits the detector is oscillated to beat with the carrier of the tone modulated wave from a standard signal generator. Regeneration is then readjusted, to a maximum without oscillation of the detector. The radio stages are then "brought into line" by the adjustment of their trimming condensers. The several by-pass condensers and choke coils shown in the system of voltage supply to the various plate circuits serve to prevent reactions through the common B battery supply.

In Fig. 21, the original portable loop developed for this job is shown. The loop itself is a one-meter-square single turn of tubing. The shielded supporting column containing the slip rings, the dial, tripod, etc., and its portable nature are clear from the photograph. In Fig. 22 is shown the SCR-173 direction finder developed by Wireless Specialty Apparatus Co. This set which followed the development of the first SCR-170 is for general direction finding and employs three loops and three tuners which are built as interchangeable drawers fitting into the chassis case. The short-wave (A unit and A loop) arrangement of this set may be employed for the same purpose as the SCR-170 receiver in tracking meteorological balloon transmitters. Thus far, however, the SCR-173 equipment has not proved as sensitive for such work and is much heavier and less portable. Briefly, the SCR-173 is a superheterodyne and has two tuning controls, one for loop tuning, the other for setting the "beating oscillator." An auxilliary antenna is used to pick up signal and combine it with the energy picked up by the loop in proper amplitude and phase to cancel out the antenna effect. The tripod, loop, and set arrangement was partly the result of a study of the first SCR-170. In turn, the final design of the SCR-170 used ideas from the 173 development. For example, the dial and handwheel are the same, having been obtained from Wireless Specialty Apparatus Co. The castings are our own design but follow, in much lighter form, the construction of the SCR-173. Ball bearings are used in all the designs to give ease and reliability of operation. A magnetic compass and peep sight, set at 90 degrees to the plane of the loop, enable the zero setting of the loop with reference to the base line (or to a North and South line) to be readily made. The dial for reading bearings has a double calibration so that the opposite "null" point can be readily checked. The dial may be rotated with reference to the loop and locked so that bearings are directly readable relative to the base line. The SCR-170 has in addition a lock to hold the loop fast, after sighting along the base line until the dial can be set and locked. The brushes are

readily accessible for cleaning. Illumination is provided for the dial and has been used, in connection with a relay, for timing the intervals at which readings are made in tracking balloons. The SCR-173 loop has electrostatic shielding. This shield is the heavy tubing of the photo-



Fig. 22

graph, the loop wires being spaced within. The tubing is broken at the top and carefully insulated at that point so that a complete loop, which would exclude all signals, cannot be formed. The shield being at ground potential assures that the capacity of the loop to ground shall remain constant as the loop is rotated.

A point of interest, the facts of which are often observed in direction finding, is that errors in direction frequently arise when the re-

ceiver is set up near metal structures or telegraph and power lines. It often happened in field tests that on receivers near telegraph lines no direction whatever was obtainable, but on moving the receiver a few yards away perfect bearings were obtained. The following explanation is believed to offer a slightly new point of view in explaining this phenomenon by the concept of a rotating field. It is probable that the loop is being energized not only by the direct wave of the transmitter but also by the same signal as picked up and reradiated by the telegraph line. When the receiver location is close to the telegraph line, the two fields may be of nearly equal amplitude. Resolving the reradiated field into components, it is evident that the loop will be affected by radiation from the direction of the transmitter, and also by a component arriving from an apparent direction 90 degrees from the transmitter's direction. The path taken by the wave traveling via the telegraph line is longer than the direct path and hence the reradiated wave differs in time phase from the direct wave. Thus we have two fields cutting the loop in space quadrature and differing in time phase. The resulting field is a rotating field (or may be spoken of as a field having circular or elliptical polarization). It is clear, from the ordinary facts of rotating fields, that an exploring cell (our loop) will show no zero whatever. As the reradiated component decreases on moving ones receiver minimum points begin to appear and when the receiver has been moved sufficiently far from the telegraph lines to make their effect negligible, the direct wave alone is received and sharp "null" points obtain.

Only a few transmitters have actually been expended in actual balloon tracking tests, but in each of these tests the transmitters have never failed. The first test ended after three minutes through the bursting of one of a cluster of four balloons, the shock of the explosion breaking the supporting antenna leg. On the second test, balloons carried the transmitter successfully aloft. Two SCR-170 direction finders at the ends of an 860-yard base line were used as well as a theodolite at each terminal. The horizontal angles were thus checked and the theodolites enabled the ascensional rate of the balloons to be determined. On this test the balloons passed behind clouds after the 13th minute and were lost by the theodolite. The radio continued to record sharply defined bearings up to the 30th minute and still held a signal at the 57th minute when the test was discontinued. Subsequent tests show that the SCR-170 will give accurate bearings from the small BC-164 transmitter determined by a "null" point which can be read to less than half a degree when the balloons are within 5 miles and useful bearings at a distance of 10 miles.

Work on the proper balloon inflation data and the use of a single

large balloon is being carried forward by the Meteorological Laboratory but this is hardly a radio problem to be included here. It should be stated, however, that the accuracy of $1/2$ to $1/4$ degree possible with

TABLE I

Minute	Theodolite Bearing	Radio Bearing	Error
1	Missed	12	—
2	60.5	24	-35.5
3	20.4	25	4.6
4	26.9	26	- 0.9
5	32.1	32	- 0.1
6	37.5	34	- 3.5
7	42.7	40	- 2.7
8	48.6	46	- 2.6
9	54.6	56	1.4
10	61.8	62	0.2
11	68.9	71	2.1
12	75.5	72	- 3.5
13	82.9	78	- 4.9
14	86.5	87	0.5
15	89.4	90	0.6
16	92.1	91	- 1.1
17	95.2	96	0.8
18	98.9	98	- 0.9
19	102.0	102	0.0
20	104.8	104	- 0.8
21	108.3	110	1.7
22	112.3	113	0.7
23	118.3	121	3.3
24	124.6	124	- 0.6
25	130.2	131	0.8
26	136.4	136	- 0.4
27	139.4	142	2.6
28	144.4	143	- 1.4
29	149.7	147	- 2.7
30	154.8	154	- 0.8
31	159.5	160	0.5
32	164.2	163	- 1.2
33	168.7	169	0.3
34	173.6	175	1.4
35	177.7	183	5.3
36	182.0	183	1.0
37	185.6	186	0.4
38	188.4	192	3.6
39	190.7	190	- 0.7
40	192.1	194	1.9
41	193.1	191	- 2.1
42	194.1	193	- 1.1
43	195.0	195	0.0
44	195.1	195	- 0.1
45	195.0	194	- 1.0
46	195.0	194	- 1.0
47	195.0	194	- 1.0
48	195.0	195	0.0
49	195.1	196	0.9
50	194.7	196	—
51	196.5	197	0.5
52	197.0	194	- 3.0
53	197.9	197	- 0.9
54	198.7	197	- 1.7
55	199.7	196	- 3.7
56	200.6	197	- 4.6
57	201.5	197	- 4.5
58	202.5	199	- 3.5
59	203.6	202	- 1.6
60	204.8	205	0.2

the direction finders does not compare with the finer determination of bearings possible with the theodolite unless a very long base line is used and in this connection a base line of 3 miles is planned for the radio method.

To meet this base line requirement a communication system is necessary to coördinate the listening stations and the central point where the transmitters are released so that the operators may know when the test is to start and take their readings simultaneously at one minute intervals. To this end a small portable transmitter operating on dry



Fig. 23

cells has been built. This transmitter enables the listening stations to be informed by radiotelephone when the balloons are to be released. Subsequently this transmitter sends out a tone modulated signal, (one dash being a warning and the second dash the time for taking the reading) at one-minute intervals. The frequency of this coördinating transmitter is set to be the same as that of the balloon transmitter so the

listening operators concern themselves only with the following of the balloon signal, and the timing signal arrives superimposed.

The following table is of readings by theodolite and direction finder, and the error considering the theodolite as correct, as recorded at station No. 2 on the third balloon test. It will be noted that the radio operator did not attempt to read to less than a degree although it is a fact that he could have read closer during the first fifteen minutes.

An observable swinging of the radio bearing over a few degrees is at times noted by the direction finder when according to the theodolite no such variations in the balloon's position is occurring. This is

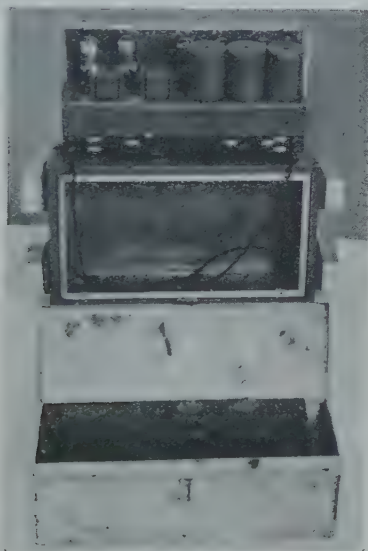


Fig. 24

attributed to wind gusts causing the antenna to swing as a pendulum. If an appreciable component of swing is in a direction at right angles to the line of direction between the balloons and the receiver, the approaching wave is shifted slightly in its plane of polarization. As is well known, a rotation of the wave's plane of polarization of 90 degrees will give a direction finding error of 90 degrees also, and hence it seems reasonable to attribute the swinging change in the bearing to this swinging of the transmitter.

It may be said in closing that the receiver for the SCR-170, independently of the direction finding input, has many features which are desirable for military radio. The receiver has therefore been adopted for other uses and with changes only as to circuit constants has become

the receiver for the SCR-132 and SCR-136 longer wave systems, as well the receiver for tank radio and for cavalry use in the SCR-163. The SCR-170 is shown as set up in the field in Fig. 23, and Fig. 24 shows the receiver as modified for tank radio.

Acknowledgement is due to many at Fort Monmouth who contributed to this project. Some early work on a miniature spark transmitter and receiver was done by L. J. Troxler, Jr. and H. Harris. In the building of the apparatus described in the paper the aid of R. I. Cohn, H. Trees, K. H. Emerson, and S. E. Spittle is gratefully acknowledged. Tests at times required the aid of a large number of the laboratory staff, as three points had to be covered in order to release the transmitter and check bearings with both radio and theodolites properly. In this connection Capt. W. H. Murphy and Paul E. Watson of the Radio Division and J. W. Goodin of the Meteorological Section, who is continuing this part of the work, aided greatly.



SOME CHARACTERISTICS OF THYRATRONS*

By

J. C. WARNER

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Summary—*The fundamental characteristics of thyratrons are discussed. Comparisons are made with characteristics of high-vacuum tubes to show the outstanding advantages and limitations of the thyatron. Starting characteristics are discussed and typical examples are shown. Several types and sizes of thyratrons are described briefly.*

MANY applications for thyratrons¹ are being found in the field of electrical engineering and, while these have not yet spread to the radio field to any great extent, it is believed that a discussion of some of the tube characteristics will be of interest to radio engineers.

The characteristics and mode of operation of the thyatron can perhaps be most easily explained by comparing it with the high-vacuum amplifier tube and showing how it resembles the high-vacuum tube in some respects and differs from it in others.

UNIQUE CHARACTERISTICS OF THE HIGH-VACUUM AMPLIFIER TUBE

The high-vacuum tube has a number of unique characteristics which have been responsible for its important place in communication engineering. Most of its applications depend upon the fact that the tube can control an amount of power in the output circuit which is much larger than that expended in the control circuit. That is, the tube is a power amplifier.

The control in the high-vacuum tube is continuous. That is, under proper conditions the output current follows the wave form of the control voltage without discontinuities.

The high-vacuum tube is independent of frequency, up to the point where the time required for an electron to go from cathode to anode becomes important.

The current flow through the tube is unidirectional. This is not always a desirable characteristic although it does not greatly handicap the use of the tube.

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¹ "Thyatron" is the General Electric name for a gas- or vapor-filled tube in which the current is controlled by means of a grid or control electrode.

LIMITATIONS OF THE HIGH-VACUUM TUBE

Theoretically a high-vacuum triode could be built to control any amount of power or current but actually there are serious difficulties in going to very high currents, that is, of the order of 50 amperes or more. In order to carry such currents the effect of the space charge must be minimized by large electrode areas or by the use of high voltages. Tubes with large electrode areas are of course costly to build and the larger the area the greater must be the spacing between electrodes which partially nullifies the effect of the large areas. Raising the voltage across the tube of course increases the losses and at currents of the order of twenty-five amperes the voltage drop may be several thousand volts. These limitations make the high-vacuum tube unsuitable for most uses where more than a few amperes are to be controlled. So, while the space charge is one of the essential factors in the fundamental operation of the high-vacuum tube, it establishes certain practical or economic limits to the design and application of the tube.

A second limitation in the high-vacuum tube is in the design of the cathode. At best the efficiency of an open electron emitter is low since most of the energy supplied is lost by radiated heat. Any attempt to reduce this radiated heat by reflectors or shields invariably increases the space charge effect.

THE EFFECT OF IONIZATION IN THE THYRATRON

The thyatron contains a low pressure of gas or vapor which ionizes whenever the voltage rises above a certain point. Mercury is most often used to supply the vapor although for some applications an inert gas is more suitable.

The ionization of the vapor neutralizes the electron space charge and leads to two important results. If the voltage across the tube is more than a certain critical value—about 15 volts for mercury—the current becomes limited only by the impedance of the external circuit, provided of course that the electron emission from the cathode is ample. The voltage across the tube is then practically constant for any amount of current.

The second effect of space-charge neutralization is that it becomes unnecessary to have the cathode open and exposed to the field of the anode as in a high-vacuum tube. This makes it possible to place heat-reflecting shields around the cathode and thereby increase the emission efficiency tremendously. While an open cathode may be expected to give a useful emission efficiency of a hundred milliamperes per watt, a heat-shielded cathode with internal tungsten heater will supply current of more than an ampere per watt.

THE ACTION OF THE THYRATRON CONTROL GRID

The purpose of the control grid is to vary the field at the cathode, somewhat as in a high-vacuum tube, but once ionization takes place the effect of any charge on the grid is neutralized by the positive ions. Thus, while the grid of the high-vacuum tube can exercise continuous control over the instantaneous magnitude of the plate current, the thyatron grid can only start the current or prevent it from starting. Once the current has started the grid cannot control its magnitude, nor stop it so long as the plate voltage is maintained. However, if the plate voltage is momentarily reduced to zero or at least below the critical voltage, the grid can regain control. If the plate is supplied with an alternating voltage the grid has a chance to gain control once in every cycle and can therefore exercise smooth and precise control of the average plate current. This action forms the basis of many applications of the tube. It is necessary, of course, that the plate voltage should remain below the critical value long enough for the space to become deionized. The time required varies from a few microseconds up to several hundred microseconds, depending on the structure of the tube.

FUNDAMENTAL CHARACTERISTICS OF THE THYRATRON

The fundamental characteristics of the thyatron may be summarized for comparison with the characteristics of the high-vacuum tube which have been given.

- (1) As in the high-vacuum tube the power controlled is much greater than that expended in the control circuit.
- (2) Control is not instantaneously continuous. The current can be started by the grid but not stopped.
- (3) With a-c plate voltage the average plate current can be controlled exactly.
- (4) Voltage drop is low and practically constant.
- (5) Cathode efficiency is high.
- (6) Plate current is unidirectional, except for small incidental effects such as deionization currents.

CURRENT-STARTING CHARACTERISTICS

In a high-vacuum tube the three coefficients, transconductance, plate resistance, and mu-factor give considerable information relative to the design of the tube and its suitability for certain applications. In the thyatron, transconductance and plate resistance have no meaning since once the discharge is started the grid no longer exerts control and the plate voltage is independent of the plate current. Furthermore,

the mu-factor has no significance except at the point just before the current starts. The term "grid-control factor" or "grid-control ratio" has sometimes been used to indicate the mu-factor at this starting point but since the ratio varies considerably with plate voltage and since the starting voltage may be either positive or negative, it has been found more convenient to express the tube characteristics in terms of the grid voltage for starting the plate current, at a given plate voltage and temperature. This starting voltage is usually expressed for at least two typical plate voltages. For example, a small tube designed for low-voltage control applications might have as part of its rating the grid voltage for starting at plate voltages of 1000 and 100.

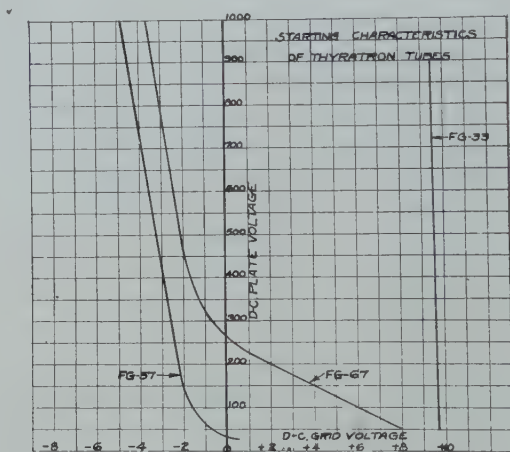


Fig. 1

The starting voltage may be either positive or negative, depending upon the structure of the tube and the plate voltage. A tube may be designed so that, within its plate voltage limits, the starting voltage is always negative, always positive, or so that it is negative for high plate voltages and positive for low. In an extreme case the positive grid voltage may be so high that ionization occurs and current starts between grid and cathode before the plate current starts.

Typical starting characteristics are given in Fig. 1 for three small tubes, one of which is shown in Fig. 2. These tubes all have the same cathode but different grids. The pressure of the vapor also has some effect in shifting the starting point, the higher the pressure the lower the plate voltage required to start the current at a given grid voltage.

THYRATRON RATINGS

There are a number of current and voltage limits which are covered by the ratings of a thyatron. Of particular importance are the maximum, average, and instantaneous currents and the maximum instantaneous inverse and forward voltages.

The maximum *average* current is determined by the allowable heating of the anode and in fact the entire bulb. Since the voltage drop is constant the anode dissipation is proportional to the average current instead of the r-m-s value. The heating of the bulb is important in the mercury vapor tube since the coolest part of the bulb determines the pressure of the vapor.

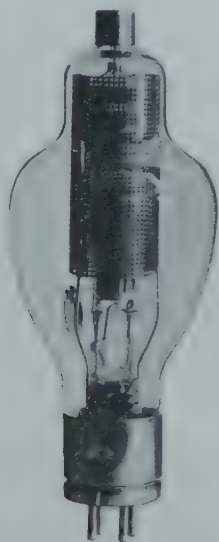


Fig. 2—This tube is actually about one-fourth the height of the tubes shown in Figs. 5 and 6.

The maximum *instantaneous* current is determined by the cathode design since the electron emission must be sufficient to supply at all times the required current.

In general the average current rating is more significant than the instantaneous current rating in indicating the size of the tube as circuit conditions often influence the permissible instantaneous current.

The maximum instantaneous inverse voltage is determined by the ability of the tube to withstand negative plate voltages. Discharges in an inverse direction are often known as "arc-backs" and the voltage at which they occur depends upon the structural design of the tube and

the pressure of the gas or vapor. The actual inverse voltage is often found to be much higher than the voltage predicted by ordinary calculations. Transients or distortion of the voltage wave form often increase the voltage far above the value calculated from sine waves.

The maximum instantaneous forward voltage is of importance when the tube is used as an inverter. It is the highest voltage at which the grid can prevent the starting of current.

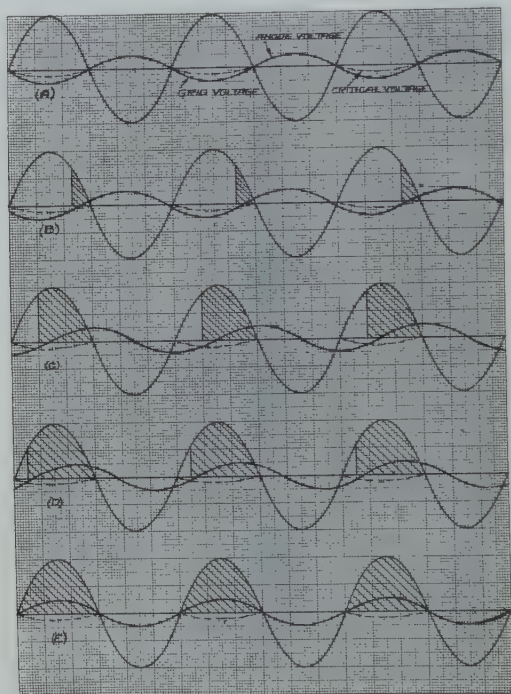


Fig. 3

THYRATRON CIRCUITS

Circuits employing thyratrons are too numerous to discuss in detail but some outstanding classes of applications will be mentioned briefly.

One of the most common applications is the controlled rectifier. Here the plate input is a-c, usually at constant potential, and the grid controls the rectified output voltage. The most effective method of obtaining the control is by varying the phase of the grid voltage with respect to the plate. If the grid voltage is in phase with the plate voltage, the full current will flow in the plate circuit. If the grid voltage is

180 degrees out of phase, no current will flow since the grid is always negative when the plate is positive. Between these two extremes the plate current can be made to start at any point in the positive half cycle and the average output current can thus be controlled as precisely as desired. Fig. 3 illustrates this type of control and shows the conditions for some intermediate values of phase difference.

The phase shift of the grid voltage may be obtained by various well-known means. A three-phase supply with a phase shifter provides a convenient method or if only single-phase supply is available the phase



Fig. 4

shift may be obtained from a bridge circuit. Another method is to add two a-c voltages which are out of phase and vary the magnitude of one of these. This varies the phase angle of the resultant voltage. Still another method is to use the combination of a d-c bias and an a-c bias which is out of phase with the plate voltage and then to vary the magnitude of the d-c bias. Controlled rectifiers can of course be designed for single-phase or polyphase circuits.

Another application is the inverter. This consists of a combination of tubes and circuits which is supplied with power from a d-c source and gives an a-c output. There are many types of inverter circuits both single phase and polyphase. These all involve the switching of the d-c line current from one tube to another by purely electrical means and thereby producing an alternating current in the output circuit. Inverters may be separately excited at the frequency desired or if the output circuit is resonant the grid circuits may be coupled to the output to produce self-excitation.

TYPICAL THYRATRONS

Thyratrons are at present made for control of average currents ranging from half an ampere up to 100 amperes. The instantaneous currents are usually from four to six times the average. The voltage

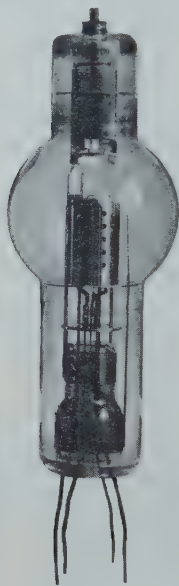


Fig. 5

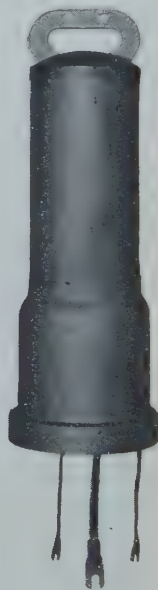


Fig. 6

limits range from 1000 to 15,000 volts. Fig. 4 shows a group of glass tubes of various sizes and Fig. 5 a glass tube which has a maximum current rating of 64 amperes average and has an inverse plate voltage limit of 15,000 volts. Fig. 6 shows a low voltage metal tube for currents of 100 amperes average.



TWENTY-WATT AIRCRAFT TRANSMITTER*

By

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Summary—A transmitter for aircraft employing cw telegraph signals only is unusually effective in performance and economical in operation. By employing a special method of screen-grid modulation, phone signaling can be provided for use when phone signaling is most needed—namely, when flying in the vicinity of airports—with almost negligible additions to the cw transmitter. A rapid transfer of information is mostly needed at or near an airport. Short-range phone signaling provides for this need. When flying on regular courses, telegraphy is rapid enough. Cw telegraph signals remain 100 per cent intelligible under conditions which would be near 0 intelligibility for the same power phone signals.

THE importance of communication with aircraft engaged in point-to-point flying has been readily recognized ever since this mode of transportation has developed into a reality. The problem of providing a practical means of communication with ground stations involves a combination of requirements that demand a number of especial considerations in design. This paper describes an aircraft transmitter developed in conjunction with the Radiomarine Corporation which is believed to contribute to this end.

A brief review of essential and desirable characteristics of an aircraft transmitter is outlined below.

1. Reliability.

(a) Simplicity.

(b) Ruggedness.

2. Sufficient performance to meet a wide scope of communication requirements.

3. Low first cost.

(a) Adaptability to a wide variety of planes to permit quantity production.

(b) Adaptability to various types of service for the same reason.

4. Practical and economical to operate.

(a) Convenience of installation and maintenance.

(b) Light weight. (Pay load capacity has been estimated to be worth from \$20.00 to \$75.00 per pound, depending upon the type of plane and service engaged in.)

An outline of the nominal ratings of the particular aircraft transmitter described in this paper is as follows:

* Decimal classification: R522.1. Original manuscript received by the Institute, May 28, 1931. Presented before Sixth Annual Convention of the Institute, June 4, 1931.

Frequency range 300 to 10,000 kilocycles, using plug-in coils.

Continuous-wave radio-frequency output of transmitter unit—20 watts.

Phone output—5 watts, 50 per cent modulated.

Power supply, derived from the plane's 12-volt battery.

Total input current to the transmitter from the 12-volt battery—24 amperes.

Type antenna, fixed for frequencies between 2500 and 10,000 kilocycles; trailing wire with external loading coil for frequencies between 300 and 2500 kilocycles.

Control for starting and stopping the transmitter, and changing from cw to phone signaling can be done remotely at the control box.

Transmitter weight—14 lbs.

Dynamotor weight— $14\frac{1}{2}$ lbs.

Control box weight— $1\frac{1}{2}$ lbs.

Key assembly—1 lb.

Antinoise microphone and cord— $\frac{3}{4}$ lb.

Low-frequency antenna load coil— $1\frac{1}{2}$ lb.

Dimensions of transmitter case— $13\frac{3}{8}$ inches long, 8 inches high, $10\frac{3}{8}$ inches deep.

Height of shock mountings—3 inches.

Dynamotor—5 inches diameter, $9\frac{1}{2}$ inches long.

Control box—8 inches long, 4 inches wide 2 inches high.

Low-frequency antenna load coil— $4\frac{1}{2} \times 4\frac{1}{2} \times 8$ inches.

The general circuit of the transmitter consists of a self-excited master oscillator and a tuned power amplifier. A modulator tube is employed for telephone signals. The antenna circuit is inductively coupled to the tuned power amplifier circuit. Adjustable inductance and capacity are employed within the transmitter to provide for resonating a fixed antenna over the band of frequencies from 2500 to 10,000 kilocycles. A UX-841 tube is employed as a master oscillator. A UX-210 tube can be used at a slightly higher plate input. Two UX-865 screen-grid tubes connected in parallel are employed as the power amplifier. A UX-171-A tube is employed to modulate the screen grids of the amplifier when phone signaling is desired. Filament power is obtained from the plane's 12-volt battery. Plate energy is obtained from the 750-volt dynamotor which operates from the same battery.

Fig. 1 is a circuit diagram of the transmitter equipment with its component parts. The master oscillator tank inductance L_1 is of the plug-in type. The power amplifier tank inductance L_2 , variable antenna coupling coil L_3 , and adjustable capacitor C_8 are a plug-in assembly. The antenna inductance L_4 and series capacitors C_9 , C_{10} ,

and C_{15} are permanently mounted in the transmitter assembly with provision for adjusting externally.

Variable capacitor C_1 serves as a trimmer by giving a small band coverage for each plug-in inductance. Intermediate points between coils and outside the range of variable capacitor C_1 are obtained by shifting a tap on the coil by means of an adjustable link attached to the coil.

The capacity range of C_s on the power amplifier coil is sufficient to cover the entire range of a master oscillator coil without tapping.

It is intended that for each operating frequency, a set of two pre-adjusted plug-in coils be used. Then to change frequency in the air (in the band 2500 to 10,000 kilocycles) it only becomes necessary to open the hinged top of the transmitter, insert the new plug-in coils, and readjust the antenna tuning circuit to resonance with the new frequency.

As an example of coverage by the above described method, seven sets of coils can be made to cover any frequency within a band of 2700 to 9700 kilocycles.

For frequencies below 2500 kilocycles, for example 600 kilocycles, an additional capacity is assembled on each coil to provide a suitable LC ratio. Each coil system is made up for one working frequency. The variable capacitor C_1 of the frequency determining circuit then serves as a vernier for adjusting to the working frequency.

The use of screen grid tubes in the power amplifier contributes greatly to a stable frequency characteristic which is recommended by Department of Commerce regulations and is a desirable factor for efficient communications.

The control box serves as a junction for all power and control circuits. These circuits are brought in through three multiconductor cables, a two-conductor to the 12-volt battery, a four-conductor to the dynamotor and a seven-conductor to the transmitter. There are two switches, two telephone jacks, a battery input ammeter and a filter capacitor mounted in the control box.

The start-stop switch marked "send-receive" closes the 12-volt battery circuit to the dynamotor, transmitter tube filaments, and antenna transfer switch. This places the transmitter in operation in approximately one second of time. The "phone" position of the cw phone switch closes the key circuit, the modulator filament circuit and the microphone supply circuit. One jack terminates the telegraph key, the other the microphone.

The ammeter indicates the input current to the set and dynamotor from the 12-volt battery.

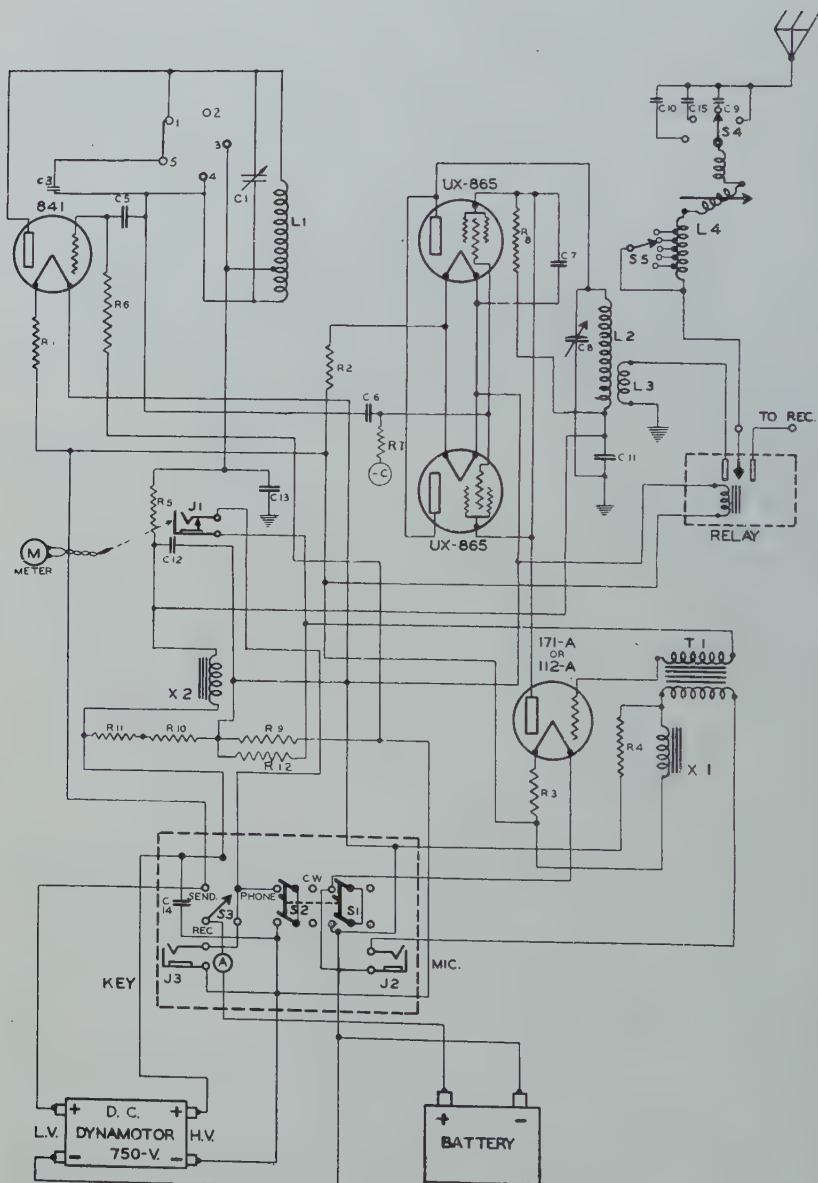


Fig. 1—Functional diagram.

The plate supply derived from the dynamotor is filtered by capacitor C_{14} in the control box, reactor X_2 , and capacitor C_{12} in the transmitter. A closed circuit jack J_1 is provided in the plate circuit of the transmitter assembly for insertion of an external milliammeter to serve as an indicator when adjusting the power amplifier tuned circuit to resonance at a predetermined frequency. A lamp of very small wattage is mounted on the front panel and is coupled to the antenna circuit so as to indicate radiation. The use of screen-grid tubes in the power amplifier eliminates any neutralizing procedure when frequency

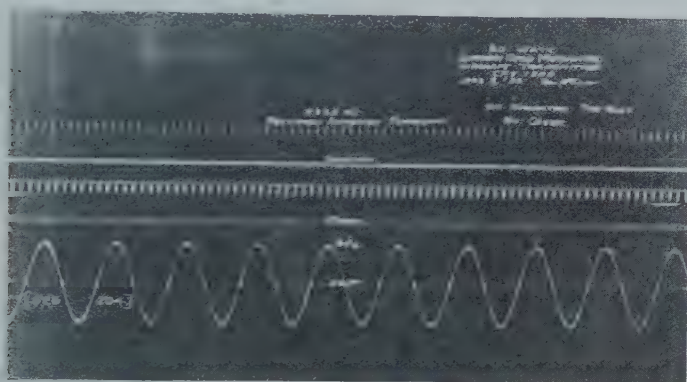


Fig. 2—Oscillogram of modulation.

or even coils are changed. This feature contributes to the assurance of a stable operating set in the field and enables a relatively rapid change of frequencies to be effected.

This transmitter is designed for phone signaling up to 40 miles. Using the screen-grid method of modulation, very little audio apparatus is necessary and there is no increase of power input. A small microphone transformer T_1 , microphone filter choke X_1 and a single UX-171-A tube is employed to modulate the screen electrodes of the power amplifier.

The screen-grid potential of the power amplifier is obtained from the plate supply through resistor R_8 . The value of this resistor is chosen to give optimum cw telegraph output. The plate of the UX-171-A modulator tube is permanently connected to the screen electrodes of the power amplifier. When the filament of the UX-171-A is energized by throwing the "cw-phone" switch to phone position, the plate resistance of the modulator tube becomes a leg of a potentiometer supplying the potential to the screen grids of the power amplifier. The plate circuit of the tube being in parallel with the power

amplifier screen circuit increases the current drain through the screen resistor R_8 , resulting in an increase of voltage drop. This, in turn, reduces the screen-grid potential to a point below the optimum value, reducing the antenna current or carrier to approximately 60 per cent of the value obtained in cw telegraph operation. When an audio voltage is impressed upon the grid of the modulator tube, its

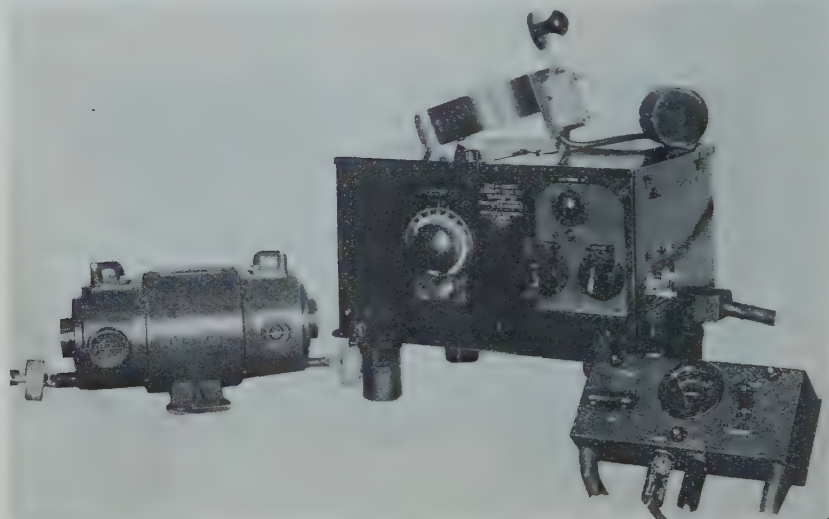


Fig. 3—Transmitting equipment.

plate resistance fluctuates so as to vary the screen-grid potential of the power amplifier at an audio rate. The maximum instantaneous voltage obtained this way will approach the optimum screen-grid potential as the instantaneous plate resistance of the modulator tube approaches infinity. The minimum instantaneous voltage will reach a value corresponding to the ratio of the minimum instantaneous plate resistance of the modulator tube and resistor R_8 . Symmetrical modulation up to 50 per cent is thus obtainable which is entirely adequate for the radiotelephone service for which this set is planned.

The microphone supply is obtained from the 12-volt battery. The circuit is filtered by reactor X_1 and resistor R_4 to minimize the effects of ripple voltages set up by the counter e.m.f. of the dynamotor. Bias for the modulator tube is obtained from the high voltage circuit by utilizing the drop of resistor R_{14} . Grid leaks which are of sufficiently high resistance to operate directly in parallel with the grids are used.

The circuits described above have thus been reduced to the simplest forms and to the minimum number consistent with the performance requirements to be met.

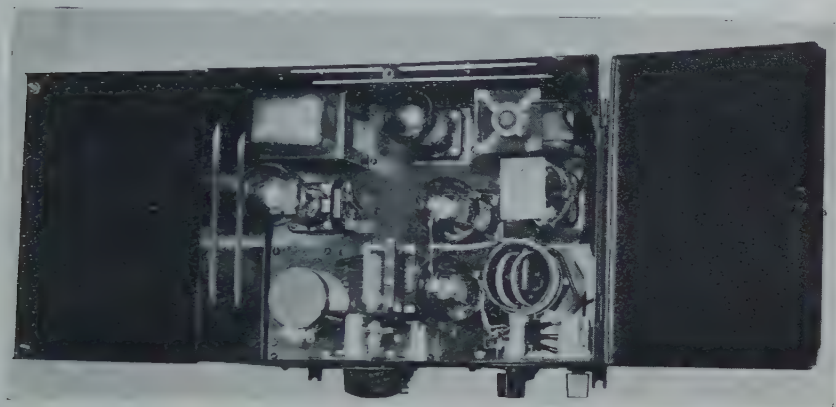


Fig. 4—Top view of transmitter (open).

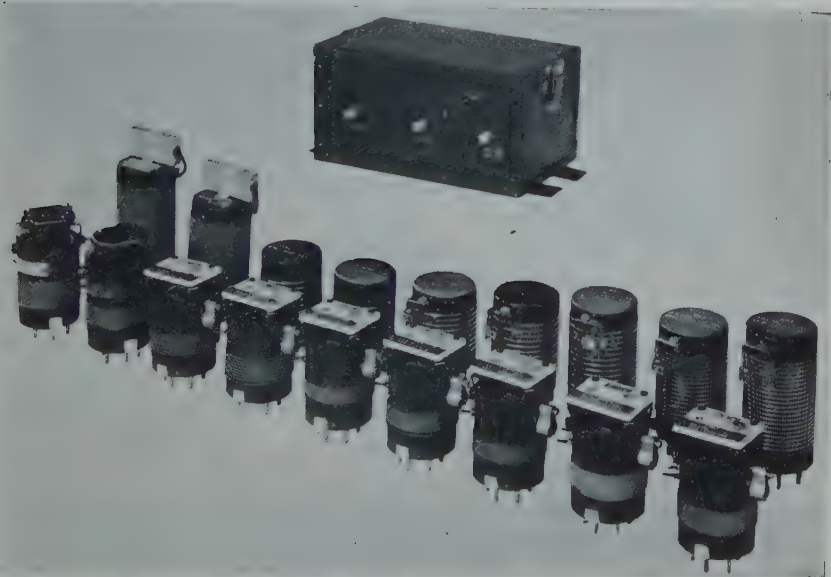


Fig. 5—Coil systems.

A view of the transmitting equipment is shown in Fig. 3. The dynamotor is equipped with locking snap-on connections to facilitate quick removal from the plane for routine maintenance of this machine.

The equipment is sprayproof construction which allows the trans-

mitter to operate despite the presence of ordinary waterspray conditions.

Ventilation is effected through small intake openings at the bottom of the transmitter assembly and louvers in the sides. The dynamotor is totally enclosed but is provided with a means for forced ventilation in case the duty cycle is to exceed 30 minutes.

The transmitter unit can be quickly detached from its shock absorber mounting by loosening two wing nuts at the bottom front of the case after removing antenna, ground connections, and the power plug.

The control box is mounted on a flat metal base. By loosening three thumb nuts and lifting the box over the three studs projecting from the base, the internal connections, switches, and jacks are made accessible.

The telegraph key is of the leg clamp type. The key and antinoise microphone are quickly attached by plugging into their respective jacks. Microphone and key cables, as well as all of the others are of weatherproof construction.

The large dial on the front of the transmitter unit controls the variable air capacitor of the master oscillator circuit. It provides a vernier adjustment to a desired frequency, and can be securely locked in place after it has been set. The other three controls provide for antenna tuning adjustments. The nine-point switch taps an inductance, the four-point provides selection of three values of series capacity, and the small knob provides a continuous adjustment of inductance between switch positions.

An open top view of the transmitter is shown in Fig. 4. The components are mounted on a metal chassis approximately 13 inches \times 10 inches \times 1 inch. Practically all of the wiring except the antenna circuit is confined below the top surface and within the chassis. Upon removal of the transmitter unit from the mounting base, the entire under surface is open, making the wiring easily accessible for maintenance purposes.

The master oscillator plug-in coil is located at the left front. The power amplifier plug-in unit is located at the right center. The modulator tube, reactors, and antenna transfer relay are located at the rear of the assembly.

Coil systems for operation at 333 kc, 500 kc, and 2700 to 9700 kc are shown in Fig. 5. The external load coil for use on 333 and 500 kc is shown at the top. The rotor coupling coil and adjustable capacitor can be seen on the power amplifier coils that cover 2700 to 9700 kc.

The transmitter equipment has been flight tested in conjunction

with Radiomarine Corporation between various points in New England on phone and cw signals. A map and chart showing distances covered over a period of several months on frequencies between 3256 and 8650 kc are shown in Fig. 6. Greater distances on cw signals were

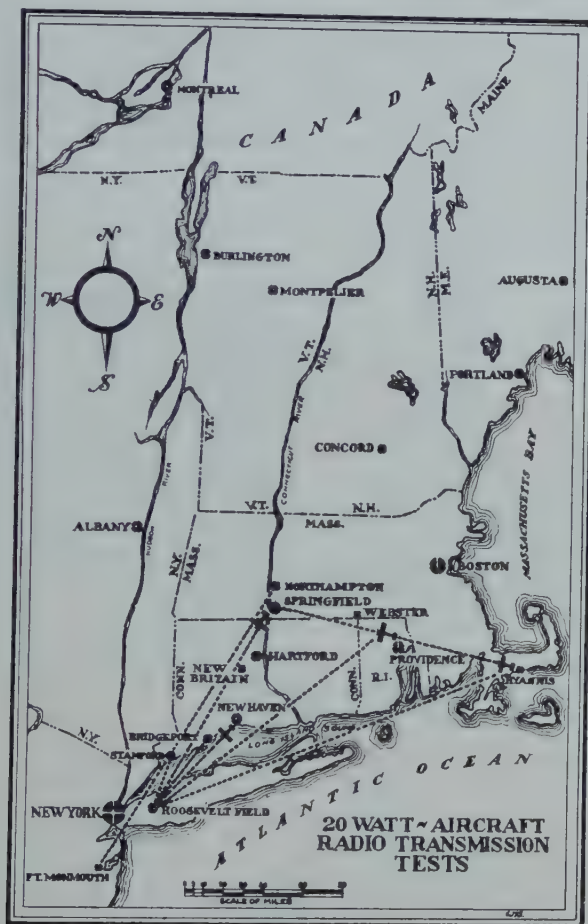


Fig. 6—Transmission tests.

not attempted at the time of these tests, but since that time a distance of 600 miles has been reported. In all cases above, a fixed type of antenna was used and in one case over 150 miles was obtained with the plane on the ground. A range of 200 miles cw may be expected at frequencies above 3000 kc.

The use of cw signaling as the major method of communication permits a simplified equipment and a great saving of weight as compared to an equipment of equal phone range.

An interesting fact when considering the two methods of communication is that heterodyne cw signals in a receiver are 100 per cent intelligible even though the noise level of the receiver is equal to several times the signal voltage. This fact enables great ranges of cw communication possible with relatively small powers. There are times, however, when a more rapid transfer of information between plane and ground than telegraph will afford would be desirable, for example, such times when a plane is nearing a port to land. Provision for short-range telephony is made in this equipment to meet this need.

TABLE I

Freq. kc.	Signal strength reported at Roosevelt Field, L. I.	Location of plane	Approx. alt.	Date	Approx. miles
3256 phone	QSA-4	Bridgeport	2000	10-20-30	38
3256 cw	QSA-5	Springfield	1500	10-20-30	108
4795 cw	QSA-5	Springfield	2000	10-21-30	108
4795 phone	Fair	Bridgeport	2000	10-21-30	38
4795 cw	QSA-5	Springfield	2000	10-21-30	108
6425 cw	QSA-5	Springfield	2000	10-22-30	108
8650 cw	QSA-5	New Britain	2000	10-22-30	77
8650 phone	QSA-4	Bridgeport	2000	10-22-30	38
8650 phone	QSA-4	Bridgeport	2000	10-23-30	38
6425 cw	QSA-5	Webster	3000	10-23-30	120
6425 cw	At Springfield—QSA-4	Hyannis	1500	10-23-30	117
6425 cw	QSA-5—R-8	Springfield	2000	10-27-30	108
6425 phone	Good	New Haven	2500	10-27-30	53
6425 phone	Good	Bridgeport	1000	10-27-30	38
6425 phone	Very good tested 5 microphones for 30 minutes	Stamford	3500	11- 7-30	25
3256 cw	Heard by RCA plane near Bal- timore	New Britain	2500	12- 9-30	255
6425 cw	Message received OK. At Ft. Monmouth, New Jersey, R-3	Northampton	0	12-11-30	157



A COURSE INDICATOR OF POINTER TYPE FOR THE VISUAL RADIO RANGE BEACON SYSTEM*

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Summary—A form of tuned-reed radio range beacon course indicator is described, called a reed converter, in which the course indications are not given by observing the two reed motions as heretofore, but by means of a zero-center pointer type indicating instrument. The motion of the two reeds generates small alternating voltages, which when rectified by oxide rectifiers and passed in opposing polarities through a zero-center indicating instrument, serve to give course indications by the deflection of the indicating instrument needle in the direction of deviation of the airplane from the course.

Each reed converter unit consists of a polarized reed tuned to one of the beacon modulation frequencies. The reed vibrates between a set of driving coils which are supplied with the signal from the radio range, and also extends between a set of pick-up coils, and generates a voltage in these coils.

Since a null method of course indication is used, it is necessary to provide a signal volume indicator in the form of a 0-500 microammeter in the output circuit of the oxide rectifiers.

Several forms of converter selector switch circuit arrangements are shown.

The advantages and disadvantages of the reed converter as compared to the tuned reed indicator are discussed.

I. INTRODUCTION

THE tuned-reed type of visual indicator¹ is used to give a pilot a visual indication as to whether or not he is flying on a specified double-modulation radio range beacon course and, if not, to which side and how much he has deviated. This type of tuned-reed indicator gives the course indication continuously by means of two vibrating reeds, the relative amplitudes of which indicate the position of the airplane with respect to the beacon course. In order to observe the reed vibration, each reed carries a white tab on its free end. These two tabs produce two adjacent white lines when the reeds vibrate. It is the relative length of these two lines which the pilot observes. Each reed is tuned to one of the frequencies of modulation used at the radio range beacon. The course is a zone of space where the strengths of the beacon modulation frequencies are equal, each zone being indicated

* Decimal classification: R526.12. Original manuscript received by the Institute, April 25, 1931.

¹ J. H. Dellinger, H. Diamond, and F. W. Dunmore, "Development of the visual type airway radio beacon system." *Bureau of Standards Journal of Research*, **4**, 425; March, 1930; RP 159; Proc. I.R.E., **18**, 796; May, 1930. F. W. Dunmore, "A tuned-reed course indicator for the 4- and 12-course aircraft radio range." *Bureau of Standard Journal of Research*, **4**, 461; April, 1930; Research Paper No. 160; Proc. I.R.E., **18**, 963; June, 1930.

to the pilot by amplitude equality of the two vibrating reeds. A deviation from the course is indicated by an increase in that reed amplitude on the side to which the airplane has deviated and an equivalent decrease in the other reed amplitude.

The development of a form of reed indicator is described in this paper in which the course indications are given by a zero-center pointer type instrument. The motions of the two reeds generate small alternating voltages, which, when rectified and passed in opposing polarities through the zero-center indicating instrument, serve to give course indications by the deflection of the indicating instrument needle in the direction of the airplane's deviation from the course. A form of course selector switch is also described which makes possible the use of this type of visual course indicator on any one of the courses of a four- or twelve-course radio range beacon in such manner that the instrument needle deflects in the same direction as the deviation of the airplane from the course, regardless of which course is being flown or the direction of flight. It is only necessary for the pilot to set the pointer of the switch to the color of the beacon course he is to fly, and to the direction of flight along this course, i.e., to "To" or "From" the radio beacon. This switch selects the proper two-reed converter units, and connects their outputs in the proper polarity to the zero-center indicating instrument, thus causing the needle to deflect in the direction of deviation of the airplane from the course. In its complete form the reed converter consists of three units, one tuned to 65 cycles, another to 86.67, and the third to 108.33 cycles. In this form it is applicable for use on the 12-course visual type radio range beacon or on four-course beacons having different combinations of the above frequencies.

II. THE TUNED REED CONVERTER UNIT

1. *Principles of Operation*

The tuned-reed converter in its simplest form is shown in Fig. 1. It consists of a polarized metal reed vibrating between two sets of electromagnet coils, one set being supplied with an alternating current of the frequency to which the reed is tuned, thus causing it to vibrate, and the other set, by virtue of the changing magnetic flux caused by the vibrating reed, generates an alternating voltage of the same frequency. At A, Fig. 1, is shown a simple reed driving unit, the magnet *T* polarizing the reed *R* with a south pole, and the pole pieces of the electromagnets *M* with a north pole. With the electromagnet coils connected in series in the proper electrical polarity, i.e., so that current flowing through them in series will tend to produce opposite magnetic polarities at the pole tips, the reed will, during one half-cycle of the driving current, be

attracted by the upper electromagnet and repelled by the lower one, thus moving up. During the second half-cycle of the driving current the net driving force reverses. Thus when an alternating current of the natural frequency of the reed is applied at AB the reed will vibrate in synchronism.

Consider this same reed, now in motion, to be moving also between a second set of electromagnet coils G , as shown at B , Fig. 1. As the reed moves up, the flux in the upper coil will increase, thus producing an e.m.f. at the upper coil terminals, and the flux in the lower coil will

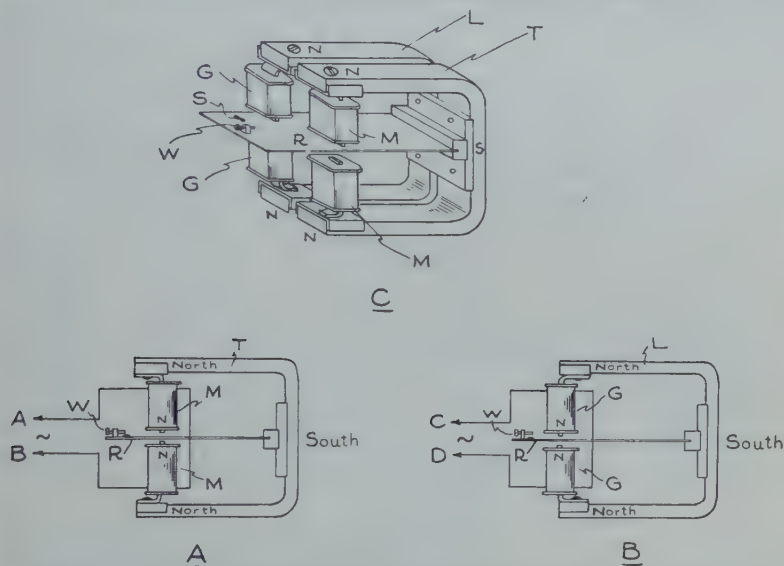


Fig. 1—The tuned-reed converter illustrating method of operation.

decrease, thus producing an e.m.f. at the lower coil terminals. If connected in the proper polarity, these e.m.f.'s will add and a voltage will be produced at the terminals CD . When the reed goes down, a voltage of opposite polarity is produced at CD . Thus the vibrating reed produces an alternating-current voltage of the frequency of vibration of the reed.

The reed converter was made by combining the one reed R as shown at C , Fig. 1, with the two sets of permanent magnets T and L . One set of coils M is supplied with the radio beacon signal modulated at the frequency to which the reed is tuned, thus causing the reed to vibrate, and thereby generating in the other set of coils G a voltage of the frequency of the vibrating reed. This reed converter therefore acts as a mechanical filter, allowing practically nothing but one frequency, that to which the reed is tuned, to pass through it.

In flight on a given radio range beacon course, two units of the type shown in Fig. 1C are used, the reed in one unit being tuned to, say, 65 cycles, with the reed in the second unit tuned to, say, 86.67 cycles. The outputs from the coils *G* in each unit are rectified by means of oxide rectifiers and the rectified voltages applied in opposition to a zero-center microammeter, as shown in Fig. 2.

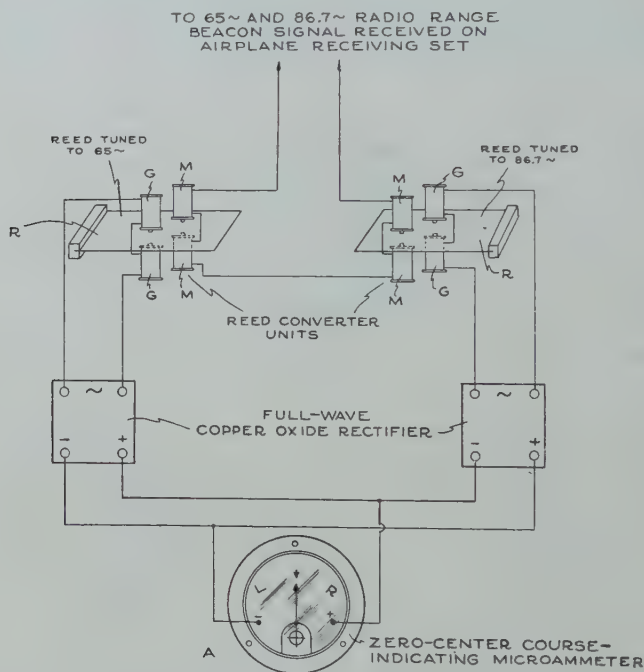


Fig. 2—The simplest form of circuit arrangement used with the tuned-reed converter.

2. Details of Design

(a) The Reed Converter Unit Design.

The reed converter unit, as finally designed, is shown in detail in Fig. 3. Fig. 4 is a photograph of the unit. The unit is mounted on a bakelite base with plug connections so that it may readily be removed from its shockproof base (not shown), so that a reed unit tuned to a different frequency may be inserted if desired. This plug-in feature also facilitates checking the reed calibration, as a spare unit may be easily inserted while the calibration check on the old unit is being made. The copper-oxide rectifier *O* is also arranged to plug into the circuit. This rectifier, which is of the type used in a-c indicating instruments, is

mounted in a small bakelite case for protection, a lock nut and screw being employed for holding the case in place. Since the rectifier operates on the output of the reed converter, it can never be overloaded, as it is rated at 5 milliamperes, and the maximum possible input which occurs as the reeds bump the pole pieces, is about 500 microamperes.

The permanent magnets *T* and *L* are made from a chromium-cobalt iron alloy known as 36 per cent "Cobalterom." They are magnetized with a polarity as indicated in Fig. 3. Two are used to keep the driving and pick-up magnetic circuits separated to prevent coupling and to in-

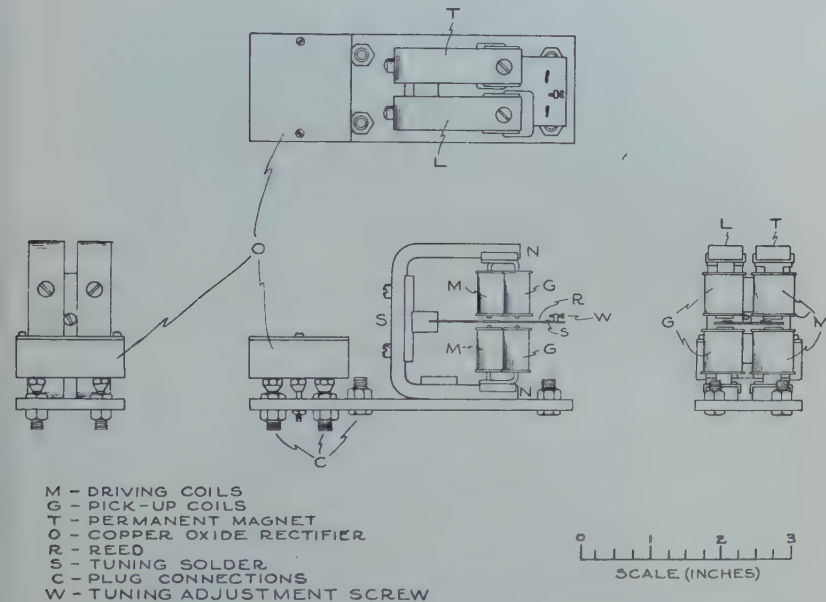


Fig. 3—Schematic diagram showing construction of tuned-reed converter unit with oxide rectifier.

crease the sensitivity. The electromagnet coils *M* and *G* are similar to those used on the Western Electric type 509-W head telephones. The pick-up coils *G* are connected in series in the proper polarity, and the reed driving coils *M* are connected either in series or in parallel in the proper polarity depending upon the impedance desired in order to match that of the receiving set output. The two pick-up coils are placed 1/16 inch from the base of the reed and the two driving coils 11/16 inch from the base.

The reed *R* is made of an alloy known as Allegheny Electric Metal. It has a magnetic permeability as good as that of steel, is rustproof, and has a modulus of elasticity, which, although not entirely independent

of temperature, is sufficiently so to allow of its use, especially with the broadness of tuning of the reed as used in this converter unit. This material is noncorrosive in ordinary climates so that its weight does not change during use. Any change in weight will of course throw the reed

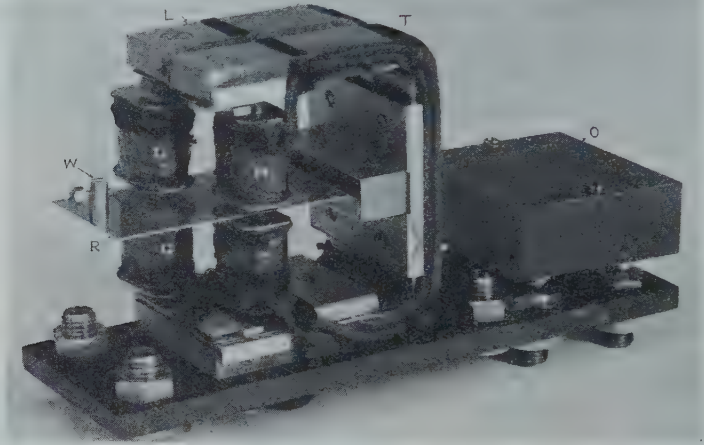


Fig. 4—A plug-in tuned-reed converter unit with plug-in oxide rectifier.

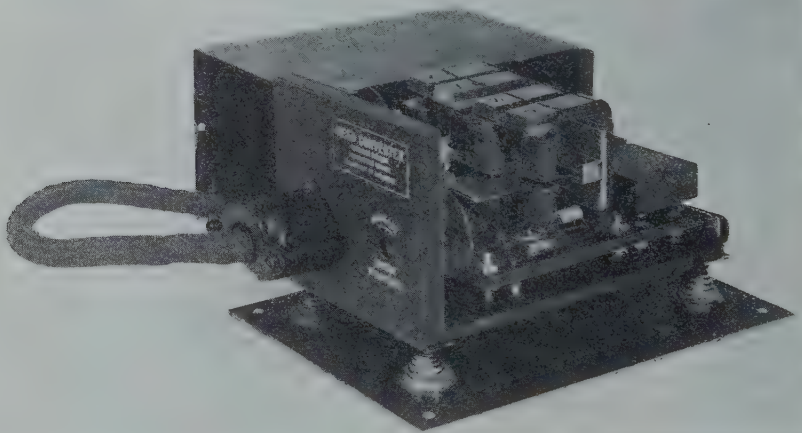


Fig. 5—Tuned-reed converters in a two-unit shockproof mounting.

out of tune. The 65-cycle reed is 2 inches long, 1 inch wide, and 0.013 inch thick. The 86.66-cycle reed is $1\frac{3}{4}$ inches long with the other dimensions the same as above. The 108.3-cycle reed is the same thickness and width but $1\frac{5}{8}$ inches long. The proper size and shape of a reed for

a given frequency may be determined mathematically.² The reeds are tuned approximately to the desired frequency by means of solder (*s*, in Fig. 3) on the end of the reed. The final tuning is done by adjusting screw *W*, Figs. 3 and 4, which is made to turn very tightly in its threaded socket so that it cannot be moved except with a screw driver. The screw and mounting are of noncorrosive material. It allows of a variation of 1.0 per cent in the tuning of the reed.

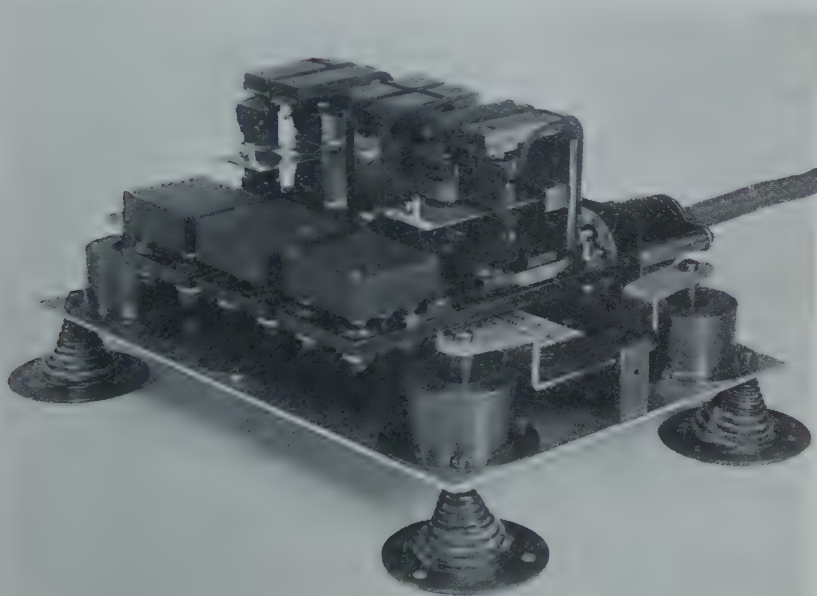


Fig. 6—Tuned-reed converters in a three-unit shockproof mounting.

The gaps between the two pole pieces of the driving electromagnets *M* control to a large degree the sensitivity of the indicator, while the gap between the pick-up coil pole pieces *G* controls the reed damping as well as the sensitivity. For one set of reed converter units constructed, in which the two driving coils were connected in parallel, 0.5-volt input to these two coils gave a deflection of 200 microamperes on the course indicating instrument. The sharpness of resonance was about 40 (see Fig. 8). In these units the gap between the electromagnet pole pieces varied between 0.04 and 0.06 inch.

² G. L. Davies, "Theory of design and calibration of vibrating reed indicators for radio range-beacons," *Bureau of Standards Journal of Research*, 7, 195; July, 1931; RP 338.

At this point it might be well to mention the effect of direct coupling between the driving coils and the pick-up coils. Separate permanent magnets for the driving and pick-up coils solved the coupling problem as the two magnetic circuits are thus practically segregated. At the frequencies used, 65, 86.7 and 108.3, the direct magnetic coupling between these coils, with the reed held stationary, is so small that it can not be measured on a 0-200 microammeter. This is with the normal input voltage to the reed converter unit which can not be exceeded due

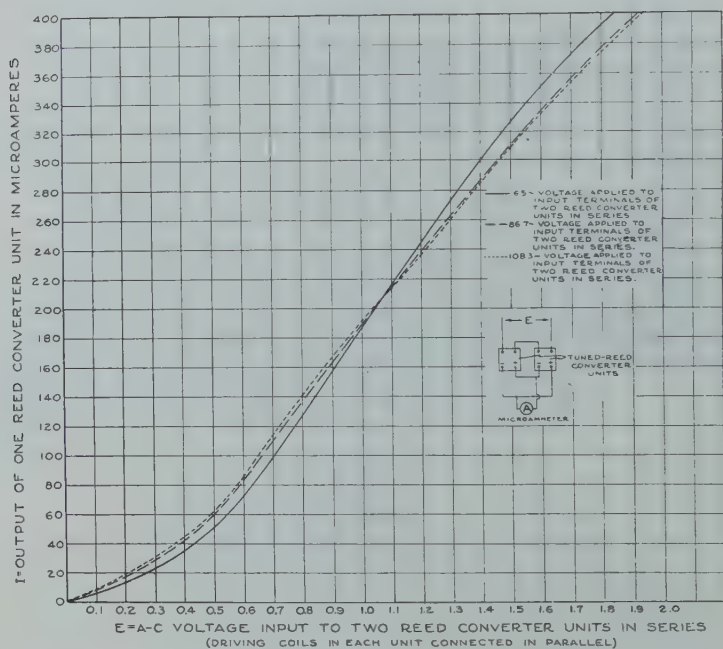


Fig. 7—Sensitivity characteristics for the 65-86.7-cycle, 65-108.3-cycle, and 86.7-108.3-cycle reed converter course indicators.

to the automatic volume control feature used on the receiving set output.³ Should an excessive interfering signal of, say, 1000 cycles be impressed on a converter unit, there is some appreciable coupling, but since two converter units are always used in series, and the output of the oxide rectifiers connected in opposing polarity, any effect from such a signal would be present in equal amounts in each converter unit and would therefore balance out. Furthermore, when used in a receiving circuit for reception from the simultaneous telephone and beacon type

³ W. S. Hinman, Jr., "Automatic volume control for aircraft radio receivers," *Bureau of Standards Journal of Research*, 7, 37; July, 1931; RP 330.

of signal,⁴ all frequencies above, say, 200 cycles are cut off from the reed converter input and are sent to the head telephones, and are therefore not present in the reed converter circuits.

(b) *The Reed Converter Unit Mounting.*

Since the least motion of the reeds in this type of reed converter induces a voltage in the pick-up coils, due to the small clearance between the reed and pole pieces, it is important that the reed be moved only by the driving coils and not by any mechanical vibration. The reed con-

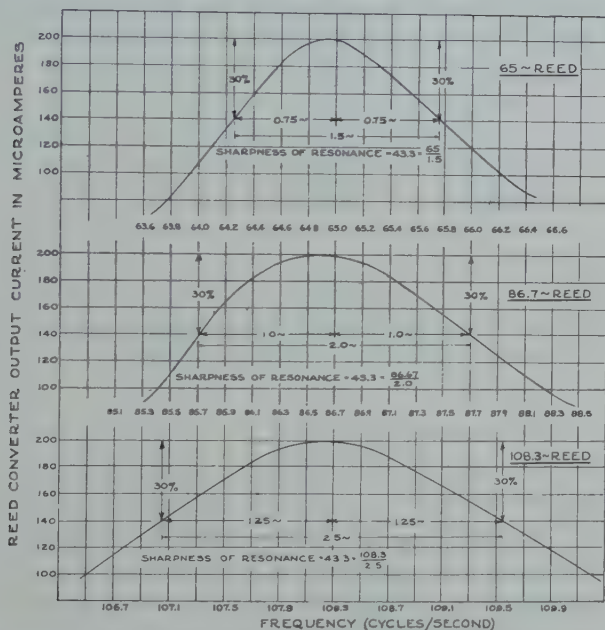


Fig. 8—Resonance curves for the three reeds in the reed converter units, showing effect of correctly proportioning the damping to keep converter outputs the same with the same percentage change in frequency.

verter units are therefore placed on a base which in turn is mounted on conical springs, stuffed with cotton for damping, as shown in Fig. 5. The two-unit mounting shown in Fig. 5. contains the plug terminals for receiving the reed converter units and the 6-terminal socket for making the necessary external connections by means of a 6-terminal plug. The 3-unit mounting requires a 10-terminal plug connection. Such a mounting containing three converter units is shown in Fig. 6. The resistance for adjusting the course sharpness (to be described later in this paper) is also placed on this mounting. It can only be adjusted

⁴ F. G. Kear and G. H. Wintermute, "A simultaneous radio telephone and visual range-beacon for the airways," *Bureau of Standards Journal of Research*, 7, 261; August, 1931; RP 331.

by means of a screw driver, since when once set to give the desired course sharpness it should not be moved.

(c) *Sensitivity.*

The gaps between the driving electromagnetic pole pieces are adjusted for each tuned-reed converter unit so that the three units will be of equal sensitivity. This adjustment is made at a normal course indicator operating current of, say, 200 microamperes. Fig. 7 shows the sensitivity curves for the three-unit combinations. The a-c input voltage was measured across two units in series, as they are used in this way in practice. The two driving coils in each unit were connected in parallel. In the region of operation of the reeds, that is, 100 to 300 microamperes, a linear relation exists between the input voltage and output current, and the slopes of the curves are about the same, which feature provides true course deviation indications as the relative value of the input voltage varies. The power input on one frequency to the two reed converters in series is about 1.0 milliwatt when an output current of 200 microamperes is obtained. This sensitivity, which is about equivalent to that of the ordinary tuned-reed indicator, has been obtained with over twice the amount of damping in the reeds. The advantage of this increased damping is discussed under the following section.

(d) *Sharpness of Resonance*

While the tuned-reed converter is about equal in sensitivity to that of the tuned-reed indicator, the amount of damping possible at this sensitivity is over twice as great. This damping, a large proportion of which is caused by the load introduced by the pick-up coils, is of course an advantage, since the modulation frequencies at the beacon need not be held to the accuracy required for the tuned-reed indicator.

The damping is so proportioned that the output from the three reed converters will not change appreciably even though the frequency varies as much as ± 1 per cent. The resonance curves for the three reed converter units are shown in Fig. 8. Since the three frequencies of modulation at the radio range beacon are obtained in most cases from three generators with 6, 8, and 10 poles, respectively, and with a common shaft connected to a synchronous motor driven from the 60-cycle line, the three frequencies must vary in the ratio of 6:8:10. Therefore, if a 0.75-cycle variation occurs in the 65-cycle frequency, a 1.0-cycle variation will occur in the 86.7-cycle frequency and a 1.25-cycle variation will occur in the 108.3-cycle frequency. From the graphs in Fig. 8 it will be seen that for such a variation in each frequency, each reed converter output drops by the same amount, that is, 30 per cent, or

from 200 microamperes to 140 microamperes. Since the relative outputs of the reed converters do not change, no apparent shift in course is caused by a variation in the 60-cycle power line frequency by as much as ± 1 per cent. A more conservative figure would be ± 0.75 per cent, however, since the resonance curves for a given reed converter may change slightly with time due to aging of the permanent magnets, etc.

A convenient method for expressing the sharpness of resonance of a tuned reed by a simple numeral has been adopted:

Sharpness of resonance = (resonance frequency in cycles/band width in cycles at 30 per cent drop in converter output from that at resonance.) From the graphs shown in Fig. 8, this figure is 43.3 in each

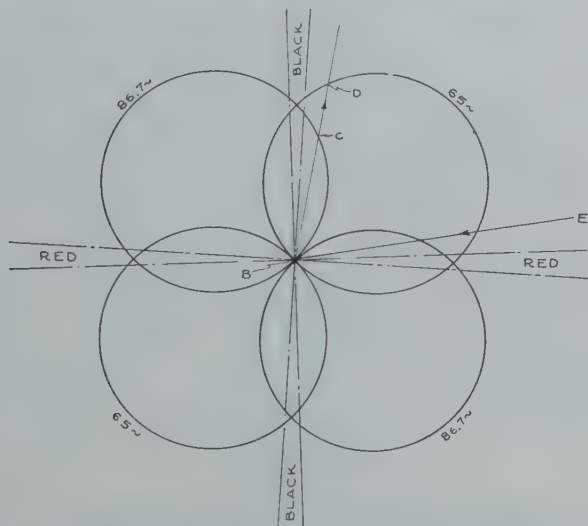


Fig. 9—Space pattern for the 4-course double modulation radio range beacon giving red and black courses.

case. This figure should be the same for each reed converter unit whenever two units are used together, as they always are in practice. For the standard tuned-reed indicator (not the reed converter type), this figure runs around 90.

III. THE COURSE SELECTOR SWITCH, DEVIOMETER, VOLUME INDICATOR, AND COURSE SHARPNESS CONTROL

1. Reed Converter as Applied to a Four-Course Radio Range Beacon

In order to show the application of the reed converter to the radio beacon courses, a typical space pattern for a four-course radio range beacon with red and black courses is shown in Fig. 9. The radio range is located at *B*. 65-cycle and 86.7-cycle modulation frequencies are used

on these courses. It is evident that the simple circuit arrangement shown in Fig. 2 makes the reed converter applicable to but one direction of flight on each of these courses, if the needle of the zero-center indicating instrument *A* is to deflect in the same direction as the deviation of the airplane from the course. Thus when going *from* the beacon on a black course, if the airplane deviates to the right and flies along some course such as *BD*, the 65-cycle signal will predominate by an amount proportional to *CD*, as shown in Fig. 9, and since the + side of the oxide rectifier in the 65-cycle reed converter unit in Fig. 2 is connected to the + side of the zero-center indicating instrument, the needle will deflect to the right. (Such instruments are wired to give

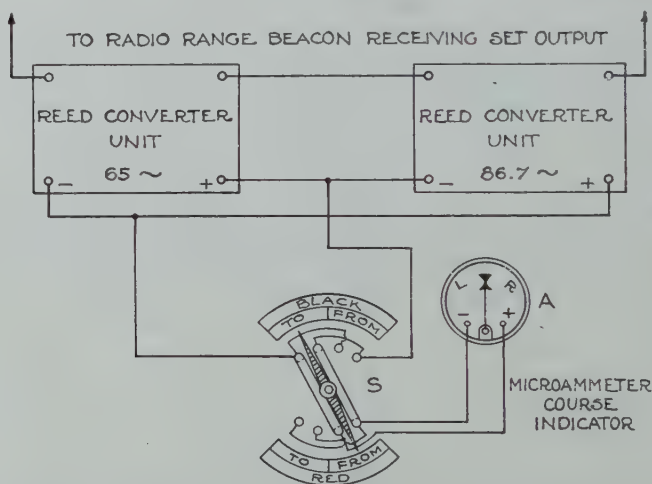


Fig. 10—Use of reversing switch in reed converter outputs in order to adapt converter to the 4-course radio range beacon.

a needle deflection to the right with a positive potential on the + terminal.) In a like manner, when going *to* the beacon on a red course a deviation to the right of the course causes a predominant 65-cycle signal and, therefore, a right-hand deflection of the indicator needle. The needle deflections are in the wrong direction when flying *to* the beacon on a black course or *from* the beacon on a red course. A simple method for overcoming this difficulty is to put a reversing switch between the oxide rectifier outputs and the zero-center indicating instrument, as shown in Fig. 10.

A color system is chosen such that the indicator needle deflection is always in the same direction as the deviation of the airplane from the course when flying in either direction on either the red or black courses. If the circuits in Fig. 10 are checked through in conjunction with Fig. 9,

it will be found that if the reversing switch *S* is set to any desired direction of flight on either of the courses (red or black) and the airplane deviates, say, to the right, the resultant polarity of the voltage impressed at the terminals of indicating instrument *A* will cause it to deflect to the right. In Fig. 10 the pointers on switch *S* are set for flying either *to* the beacon on a black course or *from* the beacon on a red course.

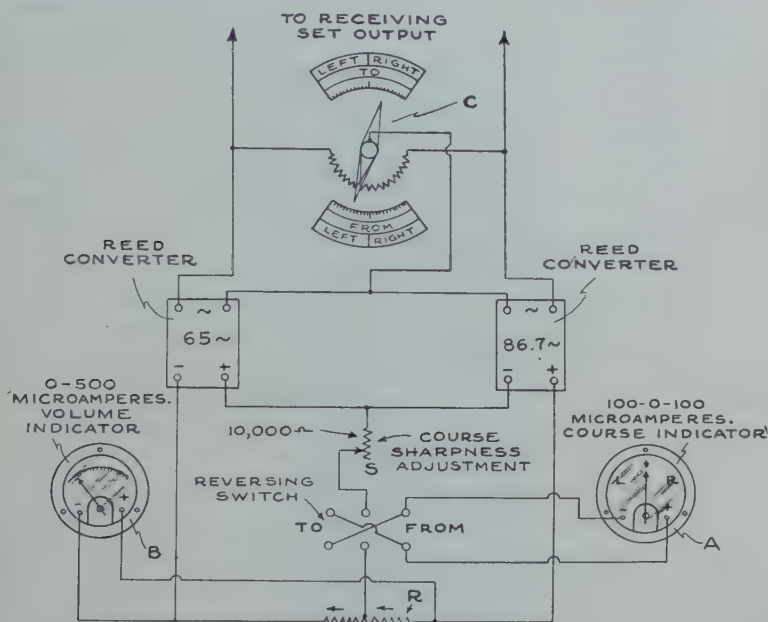


Fig. 11—Simple deviometer and volume indicator circuit arrangements for using the reed converters on a red course.

2. Use of the Deviometer, Volume Indicator, and Course Sharpness Control

(a) The Deviometer.

Before going into the application of the reed converter to the twelve-course beacon, the use of the deviometer, volume indicator, and course sharpness control will be discussed. The deviometer is used with the reed converter in the same way as with the tuned-reed indicator, its function being to enable a pilot to fly along an off-course route, yet allowing the zero-center indicating instrument to read zero when the air plane is on this off-course route. Any deviations from this route are thus indicated in the usual way. Such off-course routes may be flown along any line making an angle of up to 15 degrees on either side of the

equisignal course. The deviometer shown at *C*, Fig. 11, consists of a 10- to 20-thousand ohm resistor shunted across the two converter driving coils, with the sliding contact connected to the common connection between the two sets of driving coils. The arrangement at *C*, Fig. 11, is for a red course only. Such a double pointer and wording arrangement is necessary since the direction of movement of the sliding contact on the resistor reverses for a reversal of the direction of flight. Referring to Fig. 9, assume a pilot desired to fly along an off-course line such as *BE* on the right of the red course going to the beacon. In order to keep the zero-center course indicating instrument from deflecting to the right due to an increase of the 65-cycle signal along this route, the effective sensitivity of the 65-cycle converter driving coils is reduced by lowering the deviometer shunting resistance across these coils. This is done by moving one of the deviometer pointers, Fig. 11, to point, on the "To" scale, to the segment marked "Right." The amount of movement of deviometer *C* should be sufficient to reduce the indicating instrument deflection at *A* to the zero center when the airplane is on the new course, *BE*. The application of the deviometer and reed converter to all courses of the four or twelve-course beacon will be discussed below.

(b) *The Volume Indicator.*

One seeming disadvantage of the reed converter type of beacon course indicator is that a null method of course indication is used, which means that the beacon signal may be off, or the receiving set not functioning, yet the course indicating needle will read "on course." This cannot happen with the tuned-reed indicator as the moving reeds are always visible, indicating the presence of a beacon signal as well as the volume output of the receiving set.

A method of overcoming this difficulty is to use a second indicating instrument with a range of about 0–500 microamperes as a volume indicator. The method of connecting this instrument in the reed converter circuit is shown in Fig. 11 at *B*. A center-tap-resistor *R* of about 100 ohms is so connected to the oxide rectifier outputs that the *RI* drops across this resistance are additive so that both rectifier outputs deflect the needle of instrument *B* in the same direction. Such a system gives a positive indication that both modulation signals from the beacon are present in the reed converter circuits. Furthermore, instrument *B* indicates the volume of signal output from the receiving set; thus a beacon signal may be tuned in by watching instrument *B* until it reads a maximum as the receiving set is tuned. A normal reading for *B* is about 250 microamperes. This output level may be held in flight either

by an occasional adjustment of the volume control on the receiving set or by one adjustment in the automatic volume control unit, if such a unit is used.

There are several advantages in locating the volume indicating instrument in the position in the circuit as shown in Fig. 11, and not in the output of the receiving set or elsewhere in the receiving set circuits. First, it is located at the very end of the whole receiving circuit ar-

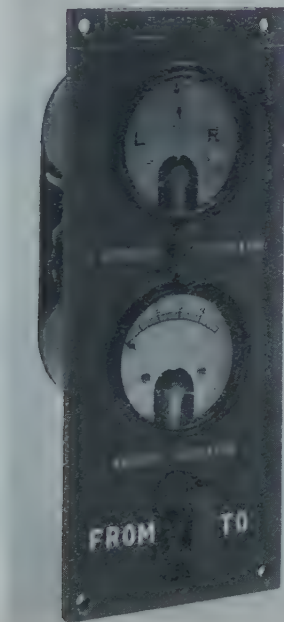


Fig. 12—Course and volume indicating instruments with reversing switch for use with reed converter on a red, brown, or yellow radio beacon course.

rangement, including the reed converter circuits, so that it will indicate a malfunctioning of any part of the complete beacon receiving system, and, second, instrument *B* is operated only by the tuned-reed outputs so that the mechanically tuned selectivity of the reeds prevents any interfering signal from operating it.

Fig. 12 is a photograph of a panel containing the course and volume indicating instruments and a reversing switch. The reversing switch is of the snap type, and may be either thrown toward the word "From" (when flying from the beacon) or to the word "To" (when flying to the beacon). The panel is wired for use when flying in either direction on a

red course. It may also be used on a brown or yellow course with the proper reed converters. By reversing the leads to the course indicating instrument, this panel may be used on a black, blue, or green course. These new courses will be discussed below.

The two indicating instruments in Fig. 12 plug into iron cans supported on the panel, making the necessary electrical connections. The cans are iron to keep strong magnetic fields from the instruments from effecting the airplane's magnetic compass. The lower can contains the resistance R , Fig. 11.



Fig. 13—Reed converter course indicating microammeter in plug-in shockproof mounting.

As the indicating instruments are the most fragile part of the reed converter apparatus, it is preferable to mount them on springs. Such a spring mounting for the course indicating microammeter is shown in Fig. 13. Fig. 14 shows a rear view of the instrument removed from its iron case holder, showing the electrical plug connections. In case an instrument is found to be defective, a new one may be immediately plugged into the holder.

(c) The Course Sharpness Control.

Unlike the tuned-reed indicator the course sharpness indication given by the reed converter is a function of the beacon signal level de-

livered to it or to the course indicating instrument. An unbalance in the course indicator with two strong output signals from the reed converter gives a much greater deflection and, consequently, an apparently sharper course. The degree of sharpness may be set to suit the pilot, either by adjusting the automatic volume control on the receiving set (or hand volume control) to change the signal level delivered to the converter or, assuming a given signal level, the course sharpness may be controlled to a large extent by means of a 10,000-ohm resistance *S*, Fig. 11, which is connected in series with the course indicating instrument *A*. The value of this resistance depends upon the sensitivity of the instrument used. By decreasing this resistance or increasing the beacon

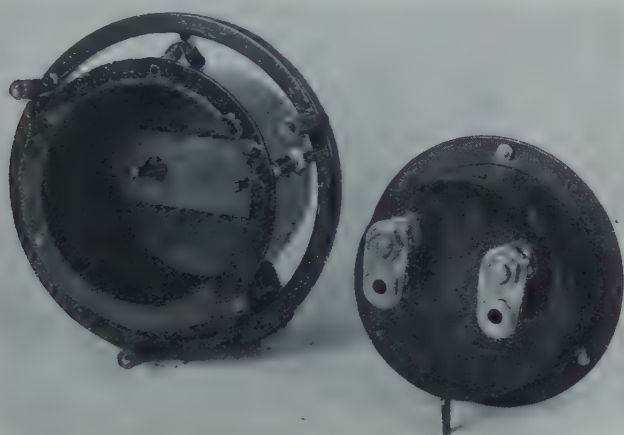


Fig. 14—Reed converter course indicating microammeter showing plug-in feature and shockproof mounting.

signal delivered to the reed converter, an apparent sharpening of the beacon course is brought about. However, in so doing, the useful portion of the beacon space pattern is reduced, since a deviation of only 10 degrees from the course may throw a 100-0-100 microampere course indicator off scale with a strong beacon signal level impressed on the reed converter, while with a weak signal and broad course indications, the needle will stay on scale for a 45-degree deviation from the course. In other words, the useful width of the beacon space pattern may be increased at a sacrifice of course sharpness. An advantage of the tuned-reed indicator over the reed converter is that it gives useful course indications up to the full width of the beacon space pattern. A method of partially overcoming this disadvantage in the reed converter is to have a course indicating instrument with a more open scale. Such in-

0-100 microammeter and an input voltage of 3.5 volts, the pilot cannot deviate more than ± 5 degrees from the true course without losing an indication of the degree of further deviation.

Satisfactory course indication for most purposes is given by using a signal volume level I_2 of 250 microamperes, which is half-scale deflection. This signal level when used with a 250-0-250 microammeter course indicator, makes possible a deviation from the course of ± 21 degrees, with correct course deviation indications throughout this range.

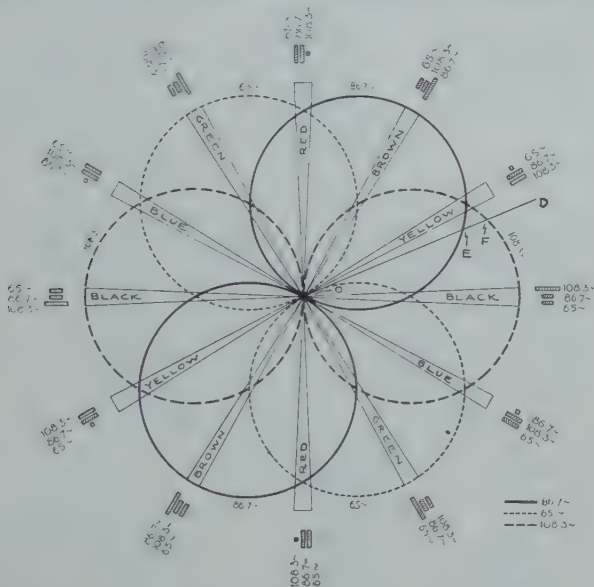


Fig. 16—The 12-course radio range beacon transmission characteristic. The colors indicate the courses where two modulation frequencies are of equal strength and reed converter outputs are equal, producing an on-course reading on the course indicator.

Instead of varying the voltage E as shown, it may be held at some value such as 3.5 volts and a similar set of graphs obtained by varying the resistance R , Fig. 15, in series with the course indicating microammeter.

From the above it will be seen that the reed converter used in the circuits as shown is very flexible in its indications and may be adjusted at will (by the pilot if desired) to suit the conditions of use.

3. Reed Converter Applied to Four- or Twelve-Course Beacon

(a) Two-Unit Plug-In Arrangement.⁵

One method of applying the reed converters for use on any course

⁵ See second paper of reference (1).

of a four-, or twelve-course beacon as shown in Fig. 16, is shown in Fig. 17. Here a double reed converter plug-in mounting, as shown in Fig. 5, is provided at A-B, into which any two converter units may be quickly plugged. With a given set of two units, the pilot may use four of the courses of a twelve-course beacon or the four courses of a four-course

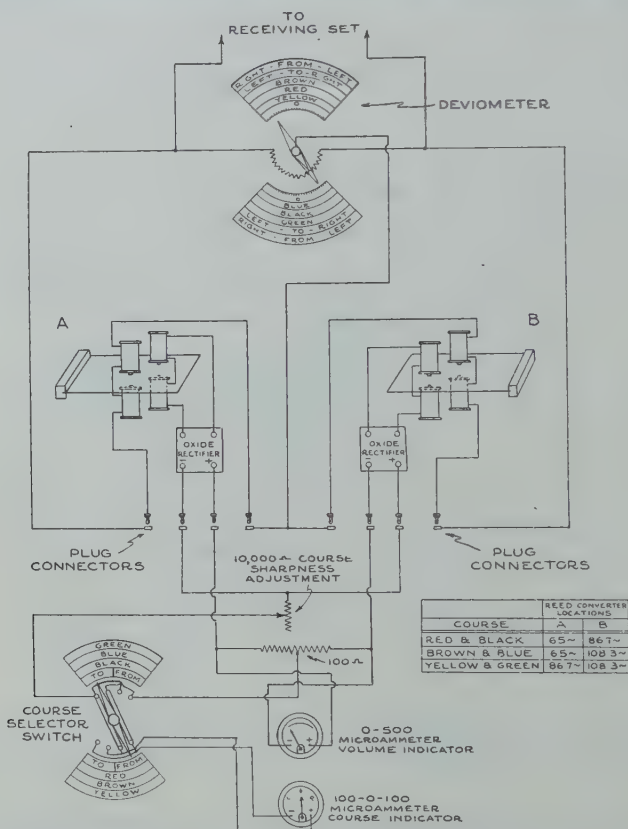


Fig. 17—Deviometer and course selector switch with color system and converter plug-in arrangement for adapting the reed converter for use in any direction of flight on any course of a 4- or 12-course beacon.

beacon. By putting a 65-cycle converter in at A and an 86.7 cycle converter at B, a red or black course may be flown. By putting a 108.3-cycle converter in place of the 86.7-cycle unit in B, a brown or blue course may be flown, or by putting an 86.7-cycle converter in at A and leaving the 108.3-cycle unit in at B, a yellow or green course may be flown. For example, let us assume that it is desired to fly an airplane over a yellow radio beacon course. Referring to Fig. 17, the chart on the

right shows that for a yellow course an 86.7-cycle converter should be plugged in at *A* and a 108.3-cycle converter at *B*. This may be done by the ground personnel. Now, let the direction of flight be *From* the beacon and let us assume that the pilot wishes to fly along the line *OD*, Fig. 16, slightly to the right of the course (airplanes going in the opposite direction flying a little to their right to avoid collision). The deviometer pointer, pointing to the yellow scale, is turned to point toward the word "Right" on the "From" scale. This increases the sensitivity of

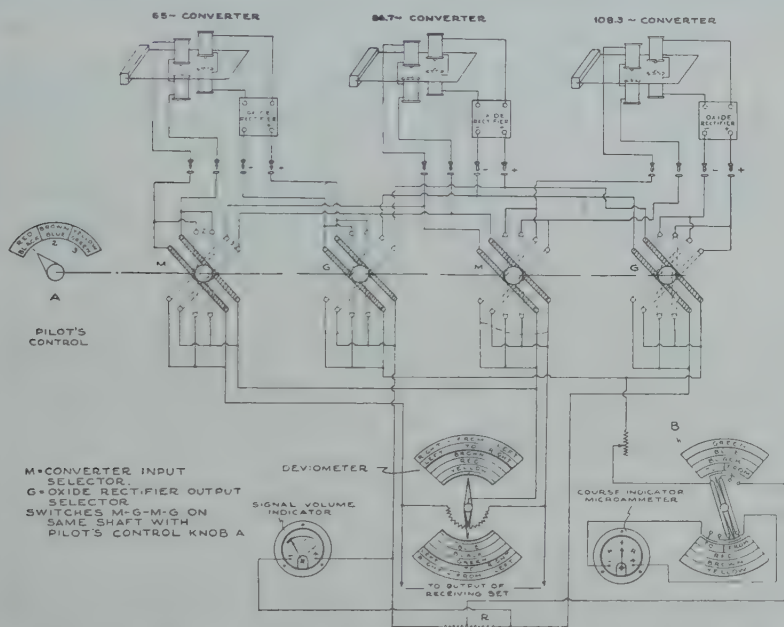


Fig. 18—Three-unit dual control arrangement for 4- or 12-course range beacon. By setting dial *A* to the color of the course to be flown the proper two reed converters are automatically connected in circuit. *B* is the reversing switch for the course indicating instrument.

the 86.7-cycle reed at *A* and decreases the sensitivity of the 108.3-cycle reed at *B*. It will be noted from Fig. 16 when going *From* the beacon (the beacon being at the intersection of all courses at *O*) on a yellow course, when deviating to the right along the line *OD*, the 108.3-cycle signal becomes greater than the 86.7-cycle signal by an amount proportional to *EF*, so it must be cut down to make them equal. This is what occurs when the deviometer pointer is moved as stated above, since a lower resistance is shunted across *B* or the 108.3-cycle reed, thus cutting down its sensitivity, and a higher resistance is shunted across *A*, the 86.7-cycle reed, thus increasing its sensitivity.

The course-selector switch must also be set so that the pointer on the yellow scale points to "From." In this position it will be noted that the positive output of the 108.3-cycle converter at *B* is connected to the + side of the course indicating instrument, thus causing it to deflect to the right, as the 108.3-cycle signal predominates over the 86.7-cycle signal.

The two-unit plug-in converter arrangement shown in Fig. 17 is applicable where a given airplane is flown over the routes of four-course beacons with the same colored courses or from one twelve-course beacon to another on the same color and 90-degree color routes; for example, airplanes flying on a transcontinental air route or on a north and south route would probably use the same color course all the way, in which case this circuit arrangement would be useful. Should the airplane fly other routes, the proper set of reed converter units may be plugged in, thereby adapting the course indicator for use on these routes. An advantage of this circuit with plug-in arrangement is that a simple form of course selector switch may be used as shown in Fig. 17.

(b) *Three-Unit Dual-Control Arrangement.*

In order to make a single reed converter installation useful on any course of a four- or twelve-course beacon at all times without any plugging in of reed converter units by the pilot or ground personnel, a three-unit circuit arrangement shown in Fig. 18 has been worked out. The selector or reversing switch and deviometer shown in Fig. 17 have been retained but a second selector switch containing the dial *A* and switches *M-G-M-G* on a common shaft has been added. The three converter units are left permanently in circuit, although they are still of the plug-in type so as to be quickly removed for replacement if necessary. The dial *A* when set to the color of the course the pilot desires to fly, connects the proper two reed converter units in circuit by means of selector switches *M-G-M-G*. Switches *M* connect the proper converter driving coils or inputs to the receiving set output, and switches *G* connect the same two converter outputs to the reversing switch and course indicator. This circuit may be checked with the aid of Fig. 16 in the same way Fig. 17 was checked with Fig. 16.

(c) *Three-Unit Single-Control Arrangement.*

A still further simplification in the use of the reed converter in application to any of the four or twelve courses is shown in Fig. 19. Here all switches have been combined into one unit on a common shaft. While the switch is a little more complicated, this is warranted since it is only necessary for the pilot to set one of two pointers on one dial *D* to

the color of the course he desires to fly and the direction he desires to fly on it. The proper two-reed converters are selected by switch *E*, and the proper common connection between them connected to the sliding contact of the deviometer by switch *F*. The proper two-converter outputs are selected by switches *I* and *J*. *J* also applies the *RI* drop across resistance *R*, Fig. 11, to the volume indicator in the proper polarity. *G* and *H* constitute the reversing switch which operates to keep the deflection of the course indicator needle in the same direction as the deviation of the airplane from the course. The deviometer, requiring

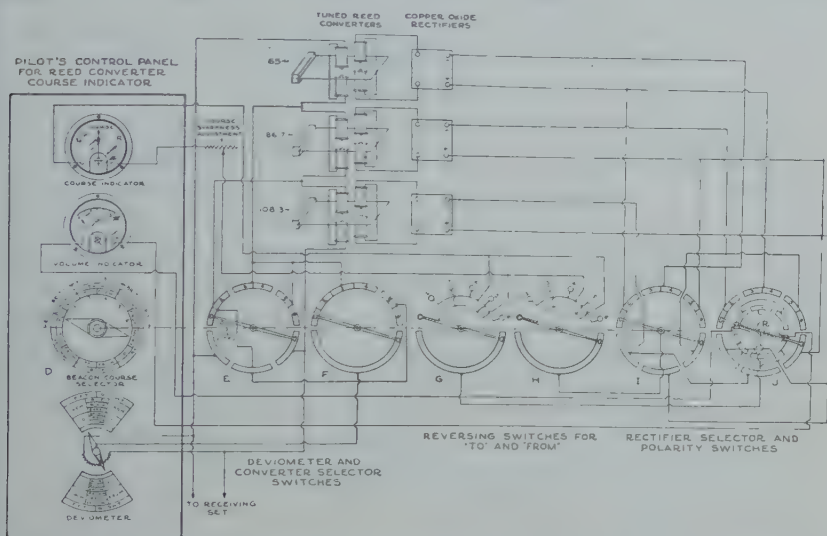


Fig. 19—Three-unit single-control arrangement for the 4- or 12-course range beacon. In this arrangement both the selector switch and the indicating instrument reversing switch are operated by one control.

separate adjustment, is on a separate shaft. The pilot's control panel with course indicator, volume indicator, course selector switch, control knob, and deviometer, is shown at the left in Fig. 19. The course sharpness adjustment may also be put on this panel if it is so desired.

IV. APPLICATIONS OF THE REED CONVERTER COURSE INDICATOR

1. As a Main Airways Beacon Course Indicator

The use of this indicator on the main long range visual type beacon has already been described under III-3. Many flight tests of the reed converter on such beacons have already been made, proving the value of the reed converter as a course indicator. The reed converter has also been used on the simultaneous radio telephone and radio range beacon.

To date several reed converter installations have been made and have proved satisfactory.

2. Use in Holding an Airplane Automatically on a Radio Beacon Course

An early application of the reed converter was realized to be that of holding an airplane automatically on a given radio beacon course. While the details of this application have not been tried, the fact that the reed converter produces a varying current output with a polarity depending upon the direction of deviation of the airplane from the

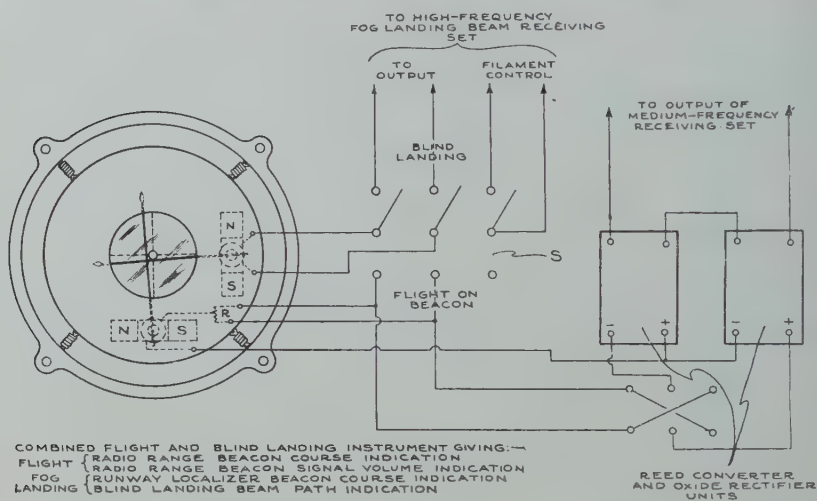


Fig. 20—Combined flying and landing instrument connected to give: (1) Main beacon course indications; (2) Signal volume indications; (3) Runway course indications; (4) Landing beam path indications.

course, makes it possible to use this current for control purposes, the airplane thereby being guided automatically in a horizontal plane along the radio beacon course.

3. Use as a Course Indicator on the Runway Localizing Beacon for Blind Landing Purposes

A valuable application of the reed converter has been found in the radio system of blind landing aids developed by the Bureau of Standards.⁶ Here the reed converter is used as a runway localizer course indicator giving indication that the airplane is over the runway (along

⁶ H. Diamond and F. W. Dunmore, "A radio beacon and receiving system for blind landing of aircraft," *Bureau of Standards Journal of Research*, 5, October, 1930; RP 238; Proc., I.R.E., 19, 585-627; April, 1931.

which the runway beacon course is oriented). Since vertical guidance is obtained by flying in on the underside of a high-frequency radio beam using as the indicator a 0-500 microammeter mounted horizontally, it has been found possible to combine the reed converter runway course indicating instrument and the fog landing beam indicating instrument into one unit, as shown in Fig. 20. Here the vertical needle is the 100-0-100 microammeter reed converter runway course indicator giving horizontal guidance, and the horizontal needle the high-frequency landing beam course indicator giving vertical guidance. With the landing airplane on both courses, the two needles intersect over the circle. The needle intersection in Fig. 20 shows that the airplane is below the proper glide path of the high-frequency landing beam, as the horizontal needle is below the circle, and off to the left of the runway course, as the vertical needle is to the left of the circle. This type of combined instrument has been found by numerous flights to be much easier to use than two separate instruments.

An advantage of the use of this combined instrument is that the 0-500 microammeter which is used to indicate the landing beam path, may perform a dual function, as shown in Fig. 20. By means of a double-pole double-throw switch this instrument may be connected either to the output of the high-frequency fog landing beam receiver and used as the landing beam course indicator when landing in fog, or it may be connected across resistance R (see also Fig. 11) in the output of the oxide rectifiers and thus may serve as the signal volume indicator. Since the signal volume indicator is not necessary when landing, the combined instrument is thus made to take the place of three instruments. Thus when flying on the main radio range beacon the vertical pointer gives course indication and the horizontal needle, signal volume indication. When landing in fog, the same two pointers are used, the vertical one now giving runway course indication since the receiving set is tuned to the runway localizer beacon, and the horizontal pointer correct landing beam path indications. By making the switch of the three-pole double-throw type as shown at S , Fig. 20, it may be made to turn on the landing beam receiving set at the same time the instrument is connected to this set.

(d) *Combination with Turn Indicator.*

Another combination of aircraft instruments made possible with the reed converter type of indicator is that of the turn indicator and the reed converter course indicating instrument. Such a combination is shown in Fig. 21, where the turn indicator is mounted in the rear of the zero-center beacon course indicator with a pointer on an extended

shaft, traveling over the same instrument face as the pointer of the course indicator. The pointers are quite different in form to avoid confusion, and travel over different scales but on the same face. This combination greatly facilitates the use of the two instruments and saves panel space.

V. COMPARISON OF REED CONVERTER WITH REED INDICATOR

1. *Advantages of Reed Converter*

- (a) Gives sharper course indications.
- (b) More easily adapted in combination with other aircraft and radio instruments.

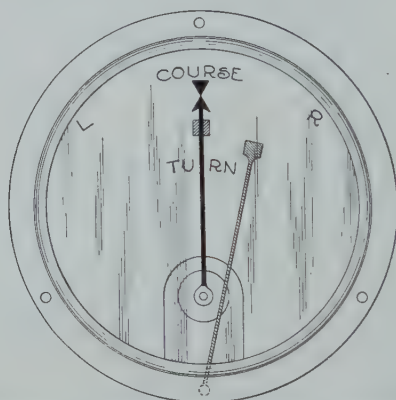


Fig. 21—The tuned-reed converter course indicating instrument combined with the turn indicator, giving both indications on one dial.

- (c) Greater damping of reeds allows of greater variation in the modulation frequencies at the beacon.
- (d) More easily adapted to the 12-course radio range beacon.
- (e) Pointer type of course indications easier to see.
- (f) Adapted to hold an airplane automatically on the course.
- (g) Easier to tune the reed to the required frequency.

2. *Disadvantages of Reed Converter*

- (a) Has six elements in place of one, as is the case with the reed indicator. These are: 2 connector units, 2 oxide rectifier units, 2 indicating instruments.
- (b) Requires the use of a delicate and sensitive course indicating instrument.
- (c) Requires an added signal volume indicator.
- (d) Motion of course indicator pointer under extreme interference, more noticeable than movement of reeds in reed indicator.

- (e) Heavier.
- (f) More costly
- (g) Calibration not as permanent.

From the foregoing it is questionable which type of course indicator is superior, but it would seem that the reed converter has a definite field of usefulness as well as the reed indicator.

VI. ACKNOWLEDGMENT

The author is indebted to H. Diamond for helpful suggestions in connection with the reed converter circuit arrangements, and to G. L. Davies for suggestions relative to the design of the reed in the converter unit.



SOME ACOUSTICAL PROBLEMS OF SOUND PICTURE ENGINEERING*

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Summary—The purpose of this paper is to point out that many advances in acoustical engineering have been necessary in order to understand and control adequately the conditions under which modern sound pictures are recorded and reproduced. To illustrate this point, some of the acoustical problems encountered at Bell Telephone Laboratories are discussed. The sudden and successive changes in sound intensity level to be expected in a room during the growth and decay of sound from an intermittent source are pointed out. The necessity of using the more general reverberation time formula, which was developed over a year ago, when dealing with comparatively "dead" rooms, is indicated. One type of acoustical distortion which is due to interference is discussed together with the measures necessary to minimize it in sound pick-up work. These phases of acoustical engineering have been selected for discussion from many which confront the engineer in this field.

THE development of the technique of sound picture recording and reproduction has presented many acoustical problems. Most of these have been concerned with improvements in the quality of recording and the illusion of reality of the reproduced sound. It was necessary to consider what acoustical conditions were required on motion picture sets for the proper recording of the sound. These involve the design and construction of the sets and the acoustical treatment which is necessary on the sound stage in which the sets are built and also the technique of proper sound pick-up by the microphone. On the other hand many theatres have been treated with acoustical materials in such a way as to reduce the reverberation time and eliminate objectionable echoes. Many of these problems are similar to those which are encountered in broadcasting and for this reason it may be desirable to review some of them.

For many years there has been an established science of acoustics which has furnished a basis for the correction of unsatisfactory acoustical conditions in many auditoriums and the proper design of others. Such a scientific background has been extremely useful in that it has served to encourage effective corrective measures and to discourage many methods of acoustical treatment which are not based on principles which are sound from an engineering standpoint. As an example of this latter type of treatment, one recalls the rather well-established idea that a multitude of wires strung overhead produce satisfactory listening conditions.

* Decimal classification: 621. 385. 96. Original manuscript received by the Institute, April 22, 1931. Presented before Sixth Annual Convention of the Institute, June 5, 1931.

In an attempt to apply this established science of acoustics to these modern problems, however, one of the first things which became obvious was that the older methods of describing acoustical phenomena were inadequate in that they did not give a sufficiently detailed and accurate picture of the situation. In order to illustrate this let us choose for discussion a few of the many acoustical problems which confront the sound picture engineer.

First, let us consider the growth and decay of sound energy in an enclosure. Fig. 1 illustrates one method of plotting the average sound intensity throughout a room against the time for a sound source which is turned on at the time $t=0$ and cut off at the time $t=0.2$. As will be seen on inspecting the curves the average sound intensity increases very rapidly at first and then much less rapidly as the average intensity

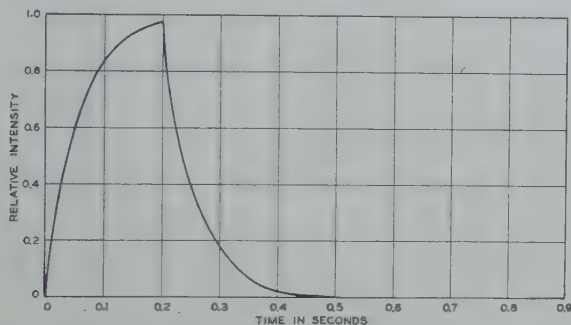


Fig. 1—Relative intensity of sound (averaged throughout the room) vs. time in seconds measured from the time the source begins to operate.

reaches the maximum value which is attained after the sound has been on long enough to establish a steady state condition. If after the steady state condition has been reached the sound source is cut off suddenly, the average sound intensity in the room will decrease in accordance with the curve shown to the right of the abscissa, $t=0.2$.

If the data shown in Fig. 1 are replotted using a logarithmic scale for the sound intensity the result is the curve shown in Fig. 2. The unit often used in this case is the decibel which is well known in acoustical circles. Since the sense of hearing exhibits approximately a logarithmic response to the stimulus of sound, this curve represents very nearly the rise and fall of the intensity level as the ear hears it, and therefore it suits our purpose better to plot the data in this way. As may be seen, the intensity level reaches a point which is within one decibel of maximum in a surprisingly short time and the decay of the average intensity level is uniform with time, that is, the plot of the decay is a straight line. The slope of this straight line indicates the rate of decay of the

sound intensity level. In a room, of given size and shape, this rate depends on the amount of sound absorption present. Since undue persistence of sound is a frequent cause of poor hearing conditions considerable importance is attached to the study of the rate of decay of sound intensity level in auditoriums. It has become conventional to describe this property of a room by stating the time it takes the sound intensity to decay to one millionth of its value after the sound source is cut off (after a steady state condition has been established), or using the scale of sound intensity level shown in the last figure, it is the time it takes the sound intensity level to decrease 60 decibels. This interval of time is called the reverberation time.

In sound picture engineering, and especially in recording, we are concerned with the variation in the intensity level at any one point in a

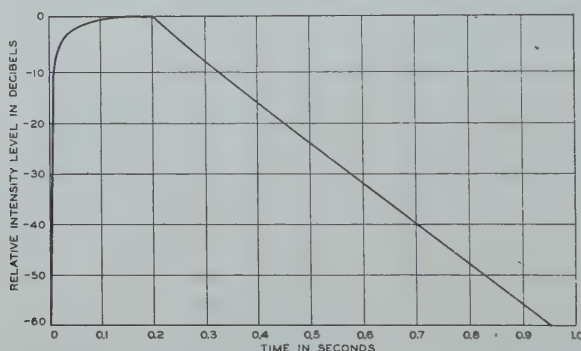


Fig. 2—Relative intensity level (averaged throughout the room) vs. time. The data shown in Fig. 1 are here plotted to a different scale of ordinates.

room. Immediately, we realize that this established method of approach is inadequate. For instance, at a point ten feet from a sound source the increase in the sound intensity would not take place the instant the source is sounded as might be inferred from the above figures but would be delayed until the sound waves have traveled the intervening distance. When this direct wave arrives there is an abrupt increase in the sound intensity followed by a further sharp increase when the reflection from the floor arrives. Fig. 3 illustrates what happens.¹ Here again, the abscissas are the intervals of time after the sound source has been started and the ordinates indicate the sound intensity level at any time. As is seen, the intensity level increases very rapidly at the moment the direct wave from the source arrives and it increases

¹ This method of analysis has been applied by R. L. Hanson of the Bell Telephone Laboratories to calculating the changes in sound intensity level at discrete points in sound picture studios and sets.

further in small increments as the floor reflection and the multitude of reflections from the walls arrive. In a very short time, however, the intensity level is very near to its maximum value. If the sound source is cut off at the time $t=0.2$, it is again a short interval of time before the end of the direct wave passes by, causing the first change in the sound intensity. There is another change when the train of waves reflected from the floor passes by and further discrete changes as the wave trains from other surfaces pass by. But soon there are so many of these and each makes such a small change in itself that the decay becomes essentially uniform with time. This part of the decay is illustrated on the curve by a straight line. Considering the sound pick-up from this viewpoint we see clearly the rapid and intermittent changes in sound intensity which are taking place.²

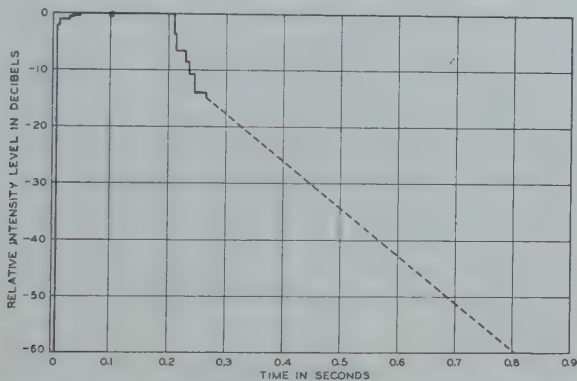


Fig. 3—Relative intensity level at a point ten feet from the source vs. time.

This last picture of the building up and decay of sound intensity level has been constructed for a simple room. In practical cases many irregularities are present. The plane surfaces of the walls may be interrupted by doors and windows. Usually the room contains furniture and there are people present. These objects will more or less scatter and diffuse the sound waves and the more they are diffused the less abrupt will be the changes of intensity level so prominent in Fig. 3.

This discussion of the rise and fall of the sound intensity in enclosures will serve to point out that the science of acoustics must be ad-

² These changes have been illustrated in Fig. 3 as successive decreases in the sound intensity level. This plot has been made without regard to the relative phases of the various wave trains. If these are taken into consideration, the magnitude, but not the time, of any particular change may be different from that illustrated. In fact, sometimes the passing of a wave train is indicated by an increase in level. This is the case when destructive interference is eliminated by the cessation of one of the interfering waves. On the whole, however, the intensity level decreases rapidly, essentially as illustrated.

vanced and extended if it is to serve the demands of modern engineering adequately.

For many years engineers concerned with applied acoustics have been active in measuring, calculating, and controlling the reverberation time in auditoriums and other enclosures. With the advent of radio broadcasting and sound pictures, activity in this field has been multiplied. Therefore, a correct reverberation time formula which may be used in designing rooms to have predetermined acoustical characteristics is much to be desired.

Until recently the formula used for this purpose is as follows:

$$T = \frac{0.05V}{a} = \frac{0.05V}{S\alpha_a}$$

in which T is the reverberation time in seconds,

V is the volume of the room in cubic feet,

a is the number of absorption units in square feet,

S is the surface of the room in square feet, and

α_a is the average coefficient of absorption of the surface.

The upper curve in Fig. 4 shows the reverberation time at various fre-

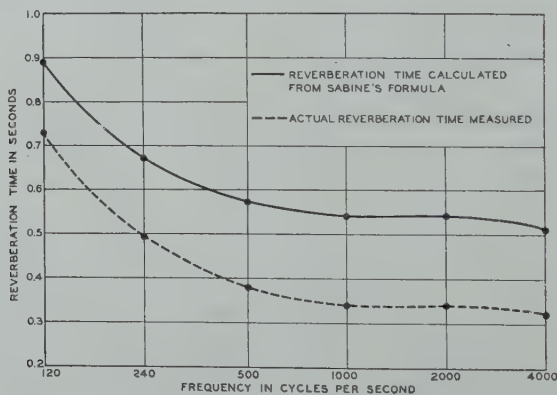


Fig. 4—Reverberation time vs. frequency for a comparatively "dead" studio.

quencies, calculated by means of this formula for the sound stage of Bell Telephone Laboratories. After the room was completed, however, equipment was available to actually measure the reverberation time at various frequencies with the results shown by the other curve on Fig. 4. It will be seen the discrepancy between the calculated and measured reverberation time throughout the whole frequency range is quite large, amounting to 50 per cent for some frequencies. Such a disparity between predicted and actual results can be quite disturbing. In this case

the solution of the problem proved extremely valuable. An extremely careful analysis of the derivation of this reverberation time formula indicated that it is applicable to "live" rooms only and that it is not suitable for rooms which are comparatively "dead" as sound stages usually are.

On the basis of these careful considerations, Eyring³ has developed a more general formula which is applicable to all rooms whether "live" or "dead." This formula is

$$T = \frac{0.05V}{-S \log (1 - \alpha_a)}$$

Comparing this to the older formula it will be noticed that the change has been to put $-\log_e(1 - \alpha_a)$ in place of α_a . For "live" rooms, where the average absorption coefficient is small, the two formulas yield results

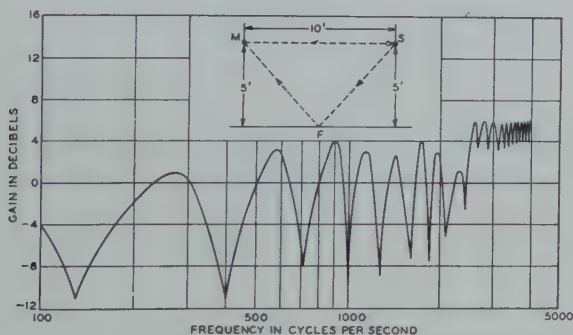


Fig. 5—Transmission frequency characteristic between sound source, *S*, and microphone, *M*, located as shown.

which are practically identical, but in the case of dead rooms where α_a is comparatively large the newer formula gives much lower values of the reverberation time than the older one and these lower values agree with those actually measured experimentally.⁴

Another acoustical problem of sound picture engineering is concerned with the amount of distortion which may be introduced into the recording system between the speaker and the microphone. Unless precautions are taken, this cause of impaired quality of the sound record may prove serious. One of the main causes of this type of distortion is the interference at the microphone of two or more sound waves com-

³ C. F. Eyring, *Jour. Acous. Soc. of Am.*, 1, 217-241; January, 1930. Fig. 4 has been taken from this paper.

⁴ It is believed by many that there is a limited range of reverberation time which is optimum for recording in any one studio. See, for instance, Maxfield and Harrison, *Bell Syst. Tech. Jour.*, 5, 493-523; July, 1926.

ing from the same source by different paths. A quantitative analysis of this type of distortion has been made by Hanson.⁵ Fig. 5 shows the transmission frequency characteristic of sound from a source S to a microphone M situated as illustrated in the sketch. In this case the direct wave travels ten feet to the microphone while the wave reflected from the floor travels about fourteen feet.

The explanation of this phenomena is simple. Since the sound waves from the source reach the microphone by two paths, one of which is longer than the other, there will be certain frequencies for which the two waves arrive in phase and there will be other frequencies for which the two waves will arrive exactly 180 degrees out of phase. On this basis we can plot a theoretical frequency characteristic of the transmission which appears in Fig. 6. The peaks of the curve appear at those frequencies for which the two waves are in phase and the valleys appear

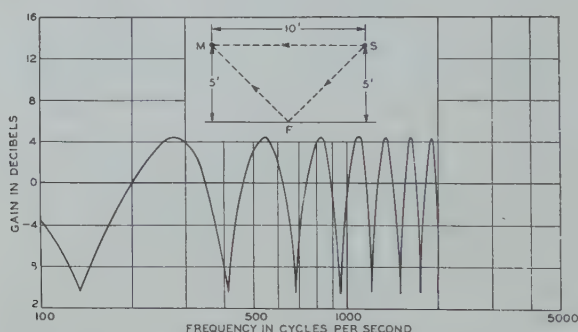


Fig. 6—Theoretical transmission frequency characteristic between sound source, S , and microphone, M , located as shown, assuming the reflecting surface to have a reflection coefficient of 0.95.

at these frequencies for which the two waves appear out of phase and partially cancel one another. It is noticed that the frequencies at which the peaks and valleys of the experimental curve occur are very nearly the same as those at which the peaks and valleys of the theoretical curve appear.

After covering the floor with very efficient absorbing material and adding a second microphone placed about fourteen feet from the source, the transmission characteristic between the source and the combined outputs of the two microphones was found to be as illustrated in Fig. 7. In this case there are two paths which the sound can take to reach the electrical recording system and the lengths of these two paths are exactly the same as those in the previous case considered, namely, ten

⁵ R. L. Hanson, *Jour. S.M.P.E.*, 15, 460-470; October, 1930. Figs. 5 to 8 have been taken from this paper.

and fourteen feet. Note that here also the peaks and the valleys come at the same frequencies at which the peaks and valleys occur on the theoretical curve. The explanation of the curve then is the same as before except that the interference takes place between the electrical outputs of the two microphones.

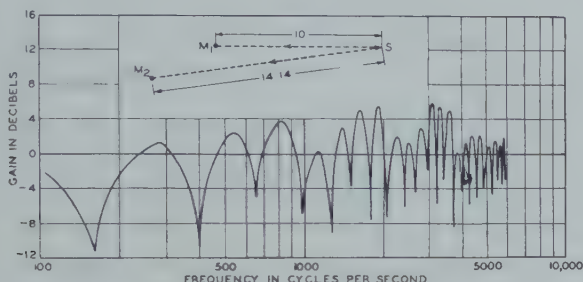


Fig. 7—Transmission frequency characteristic between a source and the combined outputs of two microphones located as shown.

Experimental sound records made under conditions where distortion due to interference existed show a very characteristic unnatural quality which is described by some as "hollow." Conditions of recording

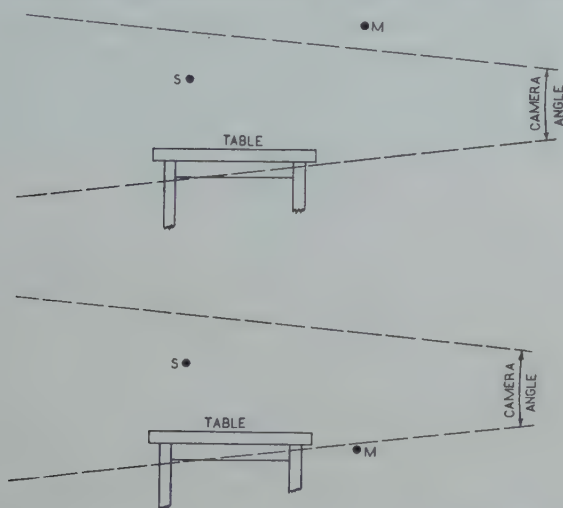


Fig. 8—The upper illustration shows an arrangement of speaker S , and microphone, M , which would result in a sound record of poor quality due to the interference at M of the direct sound and that reflected from the table. The lower illustration indicates a location of the microphone such that it receives the direct sound only.

which often lead to this distortion are found in cases where a speaker is talking near a table, a wall, or a mirror in such a way that the sound

striking the near-by surface is reflected into the microphone. One such case is illustrated in Fig. 8. The arrangement of speaker *S* and microphone *M* in the upper part of the figure illustrates a condition which would result in a sound record of poor quality due to the interference at the microphone of the direct sound and that reflected from the table. However, the position of the microphone shown in the lower part of this figure is such that the sound reflected from the table top cannot reach it. This arrangement would result in a sound record which is not affected by this form of distortion.

Acoustic distortion of this type can be avoided by the elimination of reflecting surfaces in the immediate proximity of the speaker or by a proper selection of the microphone position so that it will avoid sound reflected from these surfaces.

We have discussed the growth and decay of sound intensity in an enclosure indicating the necessity of considering the intermittent changes which occur more or less suddenly. We have seen also the necessity of using the more general reverberation time formula in modern acoustical work. The possibility of severe acoustical distortion which may occur between the source of sound and the microphone has been called to your attention. These phases of the acoustical problems encountered in sound picture engineering at the Bell Telephone Laboratories have been discussed with a view to pointing out that many advances in acoustical engineering have been necessary in order to understand and control adequately the conditions under which modern sound pictures are recorded and reproduced.



A METHOD OF REPRESENTING RADIO WAVE PROPAGATION CONDITIONS

By

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Summary—The daylight radio transmission conditions across the North Atlantic Ocean in 1930 for wavelengths of 10,000 to 20,000 m (15–30 kc) are shown in a table based on the daily observations of the signal strength of seven European high power stations taken in Washington. It is expected that similar tables of daily transmission conditions for the years beginning with 1924 will soon be ready for publication. The object of this form of tabulation is to furnish a ready means of comparison of radio conditions with other natural phenomena—sun spots, magnetic storms, weather, etc.

IN THE study of wave propagation involving the measurement of the signal strength of several stations of similar wavelength transmitting along adjacent paths, it seems desirable to average the observations from the several stations so as to represent the general conditions of transmission.

Measurements have been made at this laboratory on the daylight signal strength of a number of long-wave European stations for the past fifteen years. The number of the stations has varied, from one (Nauen, Germany, 1915–1922) to fourteen in 1930, some of which, however, do not transmit regularly enough for our purpose. In recent years these daily signal values of the different stations have been mimeographed and distributed to those interested. There has not, however, been a great enough demand for observational data of this kind to warrant the printing of such a mass of material, nor would the separate daily observations be in a particularly convenient form for study of the wave propagation conditions over the North Atlantic.

Within the last few years, considerable interest has been aroused in the study of the relationship of solar and geophysical phenomena to the propagation of radio waves, and it now seems a proper time for putting the radio data in a more convenient form for study.

If the signal intensities from the various stations studied always rose and fell together, the observations on any one station which transmitted daily would be sufficient for our purpose, but while one station, when averaged by years or even by months, may give a fair representation of conditions; in dealing with daily observations this is by no

* Decimal classification: R113.2. Original manuscript received by the Institute, May 18, 1931. Publication approved by the Director of the Bureau of Standards of the U. S. Department of Commerce.

means the case. It appears that the Kennelly-Heaviside layer is generally sufficiently nonhomogeneous to vary considerably the conditions

TABLE I
NORTH ATLANTIC DAYLIGHT RADIO TRANSMISSION CONDITIONS
1930
($\lambda = 10,000\text{--}20,000$ m, $f = 15\text{--}30$ kc).
Microvolts per Meter

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	—	31	42	42	36	—	37	63	—	81	99	57
2	29	—	—	41	40	65	81	—	47	63	—	56
3	25	42	36	11	41	49	53	58	50	59	22	62
4	35	18	34	38	—	53	—	—	48	42	22	53
5	—	29	28	40	52	52	—	—	44	—	38	50
6	41	41	46	—	37	49	—	—	53	96	35	60
7	34	38	33	42	67	61	59	—	—	82	45	61
8	27	25	27	66	48	—	47	39	53	88	47	45
9	30	—	—	59	58	—	37	—	55	102	—	40
10	—	34	40	57	31	31	42	—	59	56	27	60
11	33	31	31	45	—	40	30	45	54	61	43	57
12	—	45	33	80	50	56	35	44	51	—	41	65
13	25	14	42	—	43	48	—	56	48	47	35	61
14	19	32	43	87	44	54	—	56	—	41	26	68
15	26	43	43	76	40	—	63	63	42	43	25	68
16	53	—	—	39	38	—	57	67	44	46	41	58
17	40	50	39	44	43	—	61	—	46	56	38	58
18	21	48	58	43	—	—	56	73	38	49	39	49
19	—	36	51	55	22	32	52	88	47	—	28	85
20	39	31	38	—	38	30	—	143	45	61	37	48
21	27	29	50	58	—	43	49	46	—	61	19	45
22	21	—	61	45	—	—	50	72	54	68	18	60
23	50	—	—	39	30	—	46	92	60	74	40	46
24	39	32	27	44	50	53	44	—	62	55	34	60
25	48	37	26	—	—	35	49	84	54	55	50	—
26	—	15	30	54	40	32	54	72	45	—	60	55
27	23	29	41	—	46	33	—	80	23	44	49	63
28	—	25	45	27	35	35	38	63	—	98	46	72
29	22	—	52	45	40	—	50	72	67	55	51	58
30	13	—	—	44	—	32	58	64	62	98	73	75
31	42	—	37	—	—	—	—	—	—	48	—	40
Monthly Average	32	33	40	49	42	44	50	69	50	64	40	58

— No observation.

TABLE II
TRANSMISSION DATA

Call	Location	Approximate Frequency and Wavelength		Approximate Antenna Current I amperes	Effective Height $h(m)$	Distance from Washington d (kilometers)
		kc f	m λ			
FYL*	Bordeaux, France	15.9	18900	500	180	6160
FTT*	Ste. Assise, France	20.8	14400	350	180	6200
DFY*	Nauen, Germany	16.5	18100	400	170	6650
DFW*	Nauen, Germany	23.4	12800	400	130	6650
GBR*	Rugby, England	16.1	18600	700	185	5930
IRB	Rome, Italy	20.8	14400	500	156	7160
PCG	Kootwijk, Holland	16.8	17800	325	156	6100

* Antenna currents reported.

of absorption and reflection of signals of different wavelengths traversing adjacent paths. For example, in one month during which observa-

tions were made on twenty-six days, and during which the number of stations regularly observed about 10:00 A.M. each day varied from four to six, on only one day did all the signal strengths of the stations rise and fall together, while on eight days all but one of the stations varied together. On twelve days from one-half to two-thirds followed each other.

As Nauen is the only station which has been observed continuously during the whole fifteen years, and since it is also the station about which the most complete information regarding antenna current and antenna height has been available, it has seemed best to make this the base station for our averages. The other stations are brought to this common basis by multiplying their daily values of received field strength in microvolts per meter by the average daylight ratio of the signal strength of Nauen to the corresponding strength of the given station during all the years that the given station has been observed; corrections being applied to the observations to take account of any known changes of antenna current, if these exceed twenty per cent of the average.

In the following table the daylight North Atlantic radio transmission conditions for wavelengths of 10,000 to 20,000 m (15-30 kc) are given for the year 1930. These are expressed in terms of a station of 13,000 m wavelength (23 kc), 130 m effective height, 380 ampere antenna current, at a distance of 6650 km, measured at Washington at about 10:00 A.M. E.S.T.

The stations used in the tabulation for 1930 are Nauen, DFW and DFY, Ste. Assise, FTT, Bordeaux, FYL, Kootwijk, PCG, Rugby, GBR, and Rome, IRB.



USE OF AUTOMATIC RECORDING EQUIPMENT IN RADIO TRANSMISSION RESEARCH*

By

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Summary—This is an apparatus paper describing equipment recently developed for low frequency (17.8 kc); intermediate frequency (770 kc); and high frequency (6942.5 kc) field intensity recording. The circuits employed are presented and discussed with particular reference to expedients for obtaining nearly logarithmic scales (when used with Leeds and Northrup recording potentiometers).

Typical records obtained with the aid of the equipment described are presented and the salient characteristics of the high-frequency records (which show striking evidence of skip distance phenomena) are pointed out.

INTRODUCTION

THE history of radio transmission research furnishes ample evidence of the value of data involving series of continuous observations. However, if such measurements are attempted with apparatus requiring constant manual attention or monitoring the attendant cost of such data is very great and it is hence not surprising that the history of radio transmission measurements discloses a progressive advance in the use of automatic equipment requiring a minimum of attention and maintenance. The difficulties encountered in evolving equipment of this sort suitable for all desired types of observations are considerable, and published work familiar to the authors still leaves much to be desired from this point of view.

The rapid development in receiving equipment in the last few years, however, is constantly rendering new devices available admirably adapted to the solution of many of the difficulties encountered in the design of suitable recording equipment. The precise nature of these difficulties depends on the frequency range, etc., of the data desired and will be discussed in due course.

In transmission researches now in progress at the Electrotechnical Laboratory of Tufts College and at Newton Center, Mass., the limited personnel and funds available have rendered the development of automatic equipment essential when numerous and continuous series of observations are desired. Several features have been employed which have not, so far as the authors are aware, been published elsewhere. It is the purpose of this paper to describe the equipment in sufficient de-

* Decimal classification: R365.3×R270. Original manuscript received by the Institute, May 23, 1931. Presented before U.R.S.I., April, 1931.

tail to render these expedients readily available to others desiring to make such observations. Suggestions for further developments are also included. Observations now in progress at Tufts in which automatic recording equipment is being employed are:

- I. Field intensity and polarization of WCI (17.8 kc) as received at the Electrotechnical Laboratory, Tufts College, Mass.
- II. Field intensity of WBBM (770 kc) as received at the Electrotechnical Laboratory, Tufts College, Mass.
- III. Field intensity of WEV (6942.5 kc) as received at the Electrotechnical Laboratory, Tufts College, Mass.

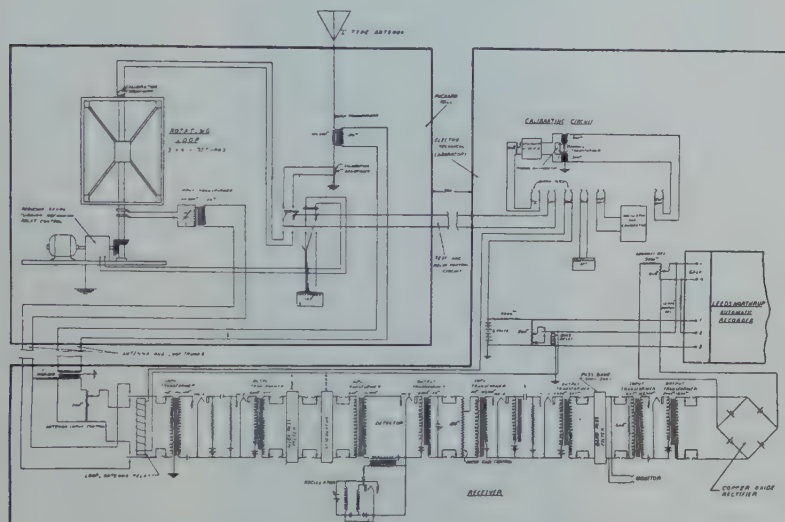


Fig. 1—Circuit of low-frequency recording equipment.

A description of the equipment employed in these projects and a description of the difficulties peculiar to each will now be described in turn.

I. FIELD INTENSITY OF WCI

These observations represent a continuation and extension of a series begun in July, 1928, at Newton Center, Mass. In the observations conducted at Newton Center, July, 1928, to December, 1929, only the field intensity on an antenna of the T type was obtained but in the series taken at Tufts observations on a loop oriented at various angles to the direction of the station (45-degree intervals) are also available. The significant characteristics of the data obtained in this series and a discussion of their interpretation have already been given

in another paper¹ together with a diagram and a brief discussion of the apparatus employed. Discussion of this project will hence be limited to a mention of certain further details peculiar to this project. A diagram and brief discussion of the circuit will be included for completeness.²

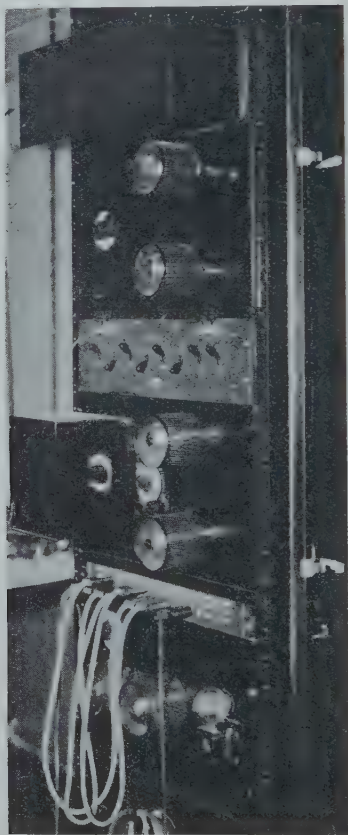


Fig. 2—Front view of low-frequency recorder.

A schematic diagram of this equipment is shown in Fig. 1 and the physical appearance of the equipment is shown in Fig. 2.

Features of interest in this set-up include the alternation of the observations on the antenna and variously oriented loop by means of relays controlled over a trunk connected at the remotely located loop to a contact mechanism driven by the same motor utilized to drive the

¹ de Mars, Kenrick, and Pickard, *Proc. I.R.E.*, **18**, 1488-1501; September, 1930.

² See also reference (1), Fig. 6, and related discussion.

same mechanism which rotates the loop. These relays shift the radio-frequency amplifier from the antenna to the loop at $2\frac{1}{2}$ -minute intervals and at the same time shift the recorder origin so as to render the records readily decipherable. The type of record obtained using this equipment is shown in Fig. 3 (showing a sample record). The antenna origin is 40 divisions and the loop is 5 divisions from the bottom of the record as indicated. Other points of interest include the use of the copper-oxide rectifier with a large external resistance inserted in series with the input to the Leeds and Northrup recorder to give a linear scale.

The large field intensity and relatively small changes in signal levels which it is usually necessary to record (about 20 db) in this project render the use of this scale quite feasible (a situation quite in contrast to that encountered in projects II and III).

It will be noted that the tubes employed in this set-up are not of the modern a-c heater type. At the time of assembly of this equipment, Western Electric tubes were selected because of their long life and constancy of emission. However, the advantage of freedom from battery maintenance was in part secured by the use of a storage battery A supply floated on the output of a tungar rectifier supplied from the a-c mains. Very good constancy of potential was thus obtained. Copper-oxide rectifiers were first employed for this purpose but they were later replaced by a tungar rectifier of greater capacity which was found to give quieter operation (particularly from the standpoint of noise in the other recording equipment located nearby). The B supply was first obtained from B batteries floated across a filter in the output of an a-c rectifier but later experience disclosed that the batteries were unnecessary and quieter operation could be obtained when they were removed, particularly if appreciable aging has occurred. For a discussion of selectivity requirements and further details in regard to this circuit the reader is referred to a previous paper.¹ The day-to-day constancy of the over-all calibration of the set-up is within 15 per cent and the absolute precision of the measurements obtained is estimated at 20 per cent.

II. FIELD INTENSITY OF WBBM

The rapid advance in the use of radio receiving equipment utilizing tubes of the heater type operating entirely from alternating current without the use of any batteries whatsoever led to an investigation of the suitability of commercial equipment of this type for use in field intensity measurements in the broadcast frequency region. Several sources of possible difficulty were considered; in particular, the pos-

¹ *Loc. cit.*

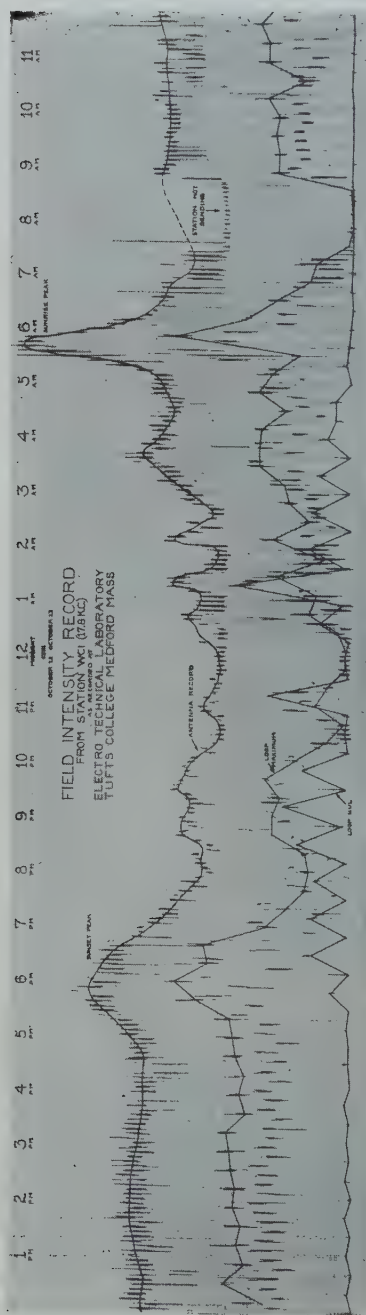


Fig. 3—Typical low-frequency recorder record. Note loop and antenna records and typical sunrise and sunset peaks.

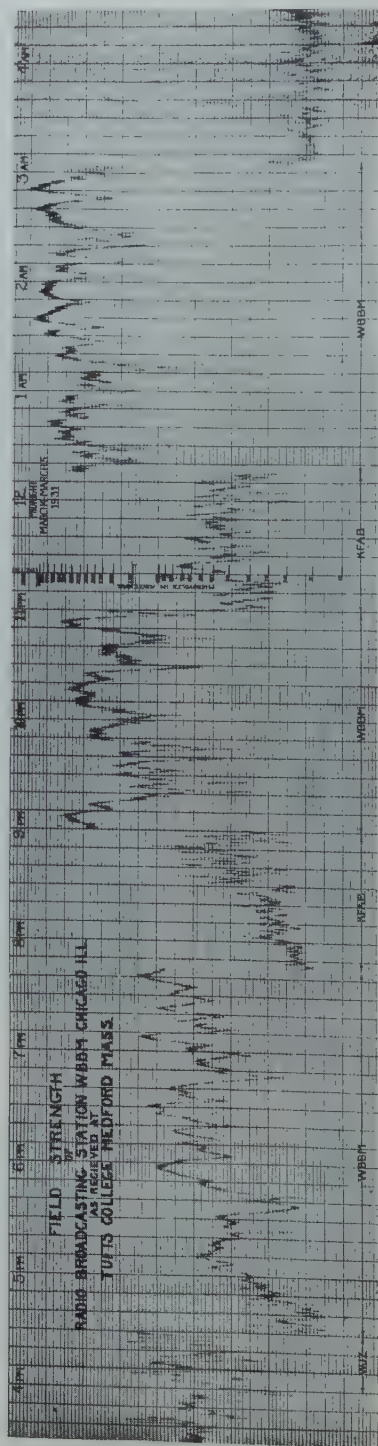


Fig. 6—Typical record obtained using broadcast recorder.

sible presence of an excessive noise level at the high gains desired due to a-c hum or other noise introduced from power supply transients. Another even more serious apprehension entertained at the start was with regard to the effect of tube aging and supply voltage fluctuations on the constancy of the calibration. Experiment with equipment of

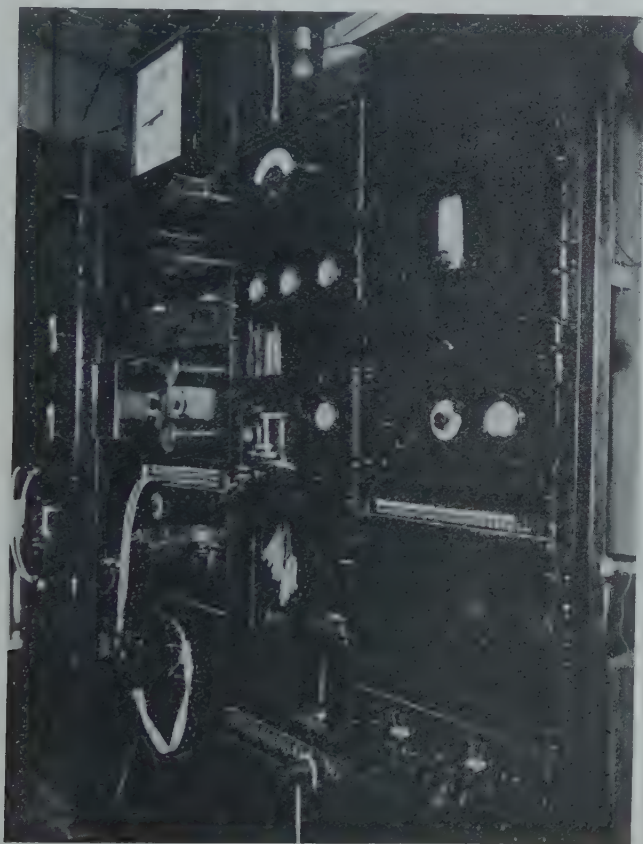


Fig. 4—Front view of broadcast recording equipment (in foreground). Note panel assembly.

this type, however, disclosed that the present state of the art rendered the use of this apparatus entirely feasible in measuring equipment. Thus, with the set-up shown in Fig. 4 giving an over-all gain of 100 db, the noise level encountered under favorable conditions from all causes was not in excess of the equivalent of 5 microvolts in the antenna (corresponding to a noise level of 1 microvolt per meter with the 5-meter effective height antenna employed). This noise level is a very favor-

able one in urban areas when only natural disturbances and inductive interference entirely external to the set-up are considered. These figures refer of course to values as registered on the recorder and not to audible responses. Perceptible a-c hum was of course encountered at many points throughout the equipment but did not appreciably impair the record.

The constancy of calibration was also very satisfactory with commercial (Champion) tubes.³ An average day-to-day constancy within

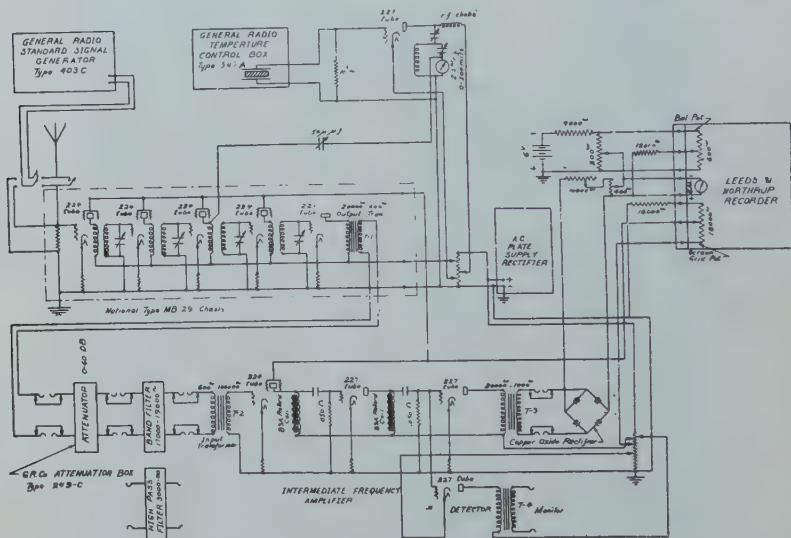


Fig. 5—Circuit diagram of broadcast recording equipment.

15 per cent was attained and an average useful tube life of well in excess of one thousand hours of continuous operation in the set-up was realized.

The apparatus and circuits employed in this equipment are shown in schematic in Fig. 5. The requirements and hence the set-ups differ from the low-frequency recorder in several important respects (beside in the use of a-c tubes). Thus, the fields observable (and measureable above the noise level) are about 10 db weaker than those which are encountered or which can be reliably recorded on the low-frequency equipment with the usual low-frequency static level. Observed and recordable variations in Project II are of the order of 50 db; under such

³ Commercial equipment employed in this set-up is freely mentioned by name throughout. This equipment was chosen on the basis of ready availability and satisfactory performance but not as the result of extended comparative tests. In fact it is believed that comparable results should be obtainable with any commercial equipment of good grade.

conditions automatic recording with a linear scale is hardly feasible⁴ and a scale calibration at least approximately logarithmic in field intensities (and hence linear in db) over the working range seems best adapted to this problem.

In the broadcast region, considerable high-frequency gain is available all assembled in the modern a-c screen grid broadcast chassis which only possesses the disadvantage of somewhat unsatisfactory selectivity for the recording of the relatively weak field received at Boston from WBBM, separated but 10 kc from the much stronger fields developed in the vicinity of Boston by WJZ. This feature rendered the use of double detection and a narrow band filter to improve selectivity desirable. The set-up shown was hence devised.

Numerous plans are available in the literature for securing wide range scales and "automatic volume control"⁵ but none seemed more flexible (at the time the circuit was evolved) than that finally employed. The wide variation of gain of screen-grid tubes with screen voltage has frequently been emphasized but the use of this characteristic in conjunction with the Leeds and Northrup recorder to secure wide range scales in the manner shown in Fig. 5 appears to be new. Thus, over a considerable range of screen voltage, the gain of the stage varies nearly exponentially with this bias (see Fig. 6) so that if the bias is made inversely proportional to the output a logarithmic, or nearly logarithmic output characteristic results.

When a Leeds and Northrup recorder is utilized, this variation of screen bias is readily secured from an additional high resistance potentiometer on the same shaft as the moving potentiometer which balances the instrument. By proper poling, (see Fig. 5) this additional potentiometer may be used to reduce the voltage on the screen grids of screen-grid tubes in proportion to the increase in the reading of the recorder. In practice the range of the scale covered may be controlled by varying the number of screen-grid stages on which the variable voltage is impressed and by introducing a constant bias in series with the screen voltage controlled by the potentiometer so that the resultant screen-grid bias is not reduced to zero at full scale reading on the recorder. Such an additional bias (which is supplied in Fig. 5 by the

⁴ A limited degree of automatic recording was obtained in earlier set-ups by use of linear scales and manually controlled stepped gain. A further development contemplated the use of linear scales and automatically controlled stepped gain. The writers believe the type of record obtained by the db scale to be fully as significant and easier to visualize and reduce than such records. However, the use of manual monitoring of course seriously limited the duration of the observations possible with limited personnel and funds.

⁵ See for example Ballantine, "Variable-mu tetrodes in logarithmic recording," *"Electronics,"* January, 1931.

12,000 ohm resistance in series with the extra potentiometer) is also necessary in order to avoid severe hunting which otherwise results at near full scale due to the very rapid change of gain with deflection encountered there. In the recorder set-up shown, a nearly uniform range of 40 db is obtained between deflections of 10 scale divisions and 90 scale divisions on the recorder with a screen bias of 60 volts at zero

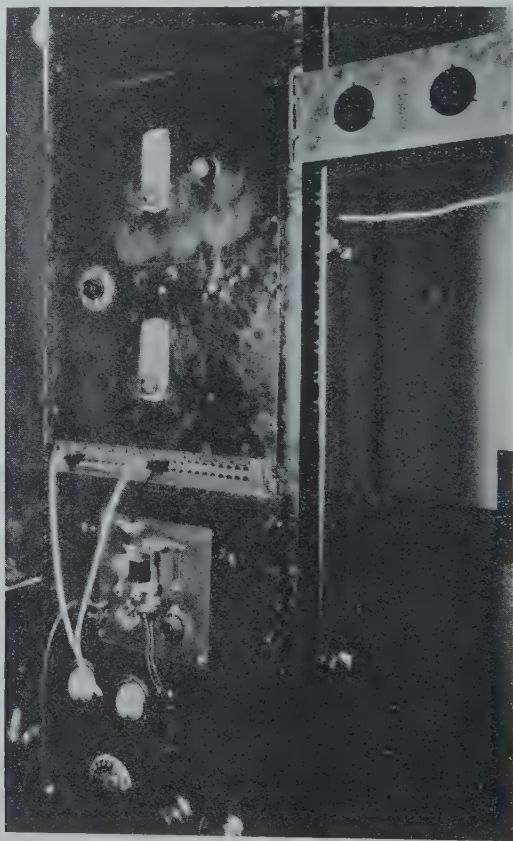


Fig. 7—View of high-frequency recorder.

deflection (zero line 10 small divisions up) and of 25 volts at full scale deflection (90 divisions range). This calibration is indicated in Fig. 6 which shows an actual record of WBBM's field. The scale noted on the left is calibrated in microvolts in the antenna. The physical appearance of the apparatus is shown in Fig. 5.

In order to insure sufficient selectivity to avoid interference from adjacent channels a filter with 2000 cycles pass-band width (1000

cycles from carrier) was introduced. This of course excludes modulation components above this value which would not, however, appreciably change the average values recorded. The quality observed audibly in the monitor is intelligible for moderately strong fields but is of course not good. Complete absence of interference from adjacent channels is achieved and a marked reduction in noise level attained. This no doubt accounts for the favorable noise levels observable.

In order to secure sufficient frequency stability for the low 18-kc intermediate frequency and narrow filter a crystal temperature controlled oscillator operating at 752 kc at 50 degrees Centigrade is employed. The set-up may be and (during the daytime) is also employed for recording WJZ on 760 kc. In this case absence of powerful interference on contiguous channels renders the selectivity obtainable in the broadcast chassis adequate. The 17-19-kc filter is hence patched out and the 3000- ∞ \sim high-pass filter substituted which readily passes the 8-kc intermediate frequency used in this work.

Gain is conveniently and metrically controlled by means of the General Radio 60-db attenuator. This makes a check possible on the relative accuracy of readings taken at varying input calibration voltages and allows a raising or lowering of recorded scales by any desired number of decibels. This feature is identical with that incorporated in the WCI recorder and has been found extremely useful. The very satisfactory copper-oxide rectifier and its associated output circuit first employed there is also preserved without essential change in this set-up. The copper-oxide rectifier is found to be quite satisfactory at 20 kc but would not of course be adapted for direct rectification of broadcast frequencies because of its excessive capacitive reactance under such conditions. The detailed output circuit is shown. (For further values of constants see Fig. 1.)

Absolute calibrations (in terms of microvolts in the antenna) are obtained with the aid of the General Radio standard signal generator, the output of which may be introduced directly in series with the antenna and the set. Comparative calibrations (for testing daily variations in sensitivity) are better obtained with the generator connected directly across the set, i.e., with the D.P.D.T. switch thrown to the left. This reduces the input impedance to the first grid and practically eliminates stray pick-ups due to imperfect shielding of the generator and stray capacity effects experienced in the other method of calibration. For reasonably large input voltages the two methods check within less than 1.5 db. Calibrations for low input voltages are impossible with the series connection because of the effects mentioned.

As will be noted in Figs. 5 and 8, important points in the circuit are rendered readily available by the use of jacks for tests or special hook-ups and the panel type of assembly is as far as possible preserved.

Checks of this set-up with observations taken at Newton Center give an average agreement over long periods within ± 20 per cent in absolute field although the short period fading as observed at the two points is quite incoherent.

The authors extend thanks to the Carnegie Institution, Department of Terrestrial Magnetism, for yearly grants which have been utilized to continue these observations. A nearly unbroken series is hence avail-

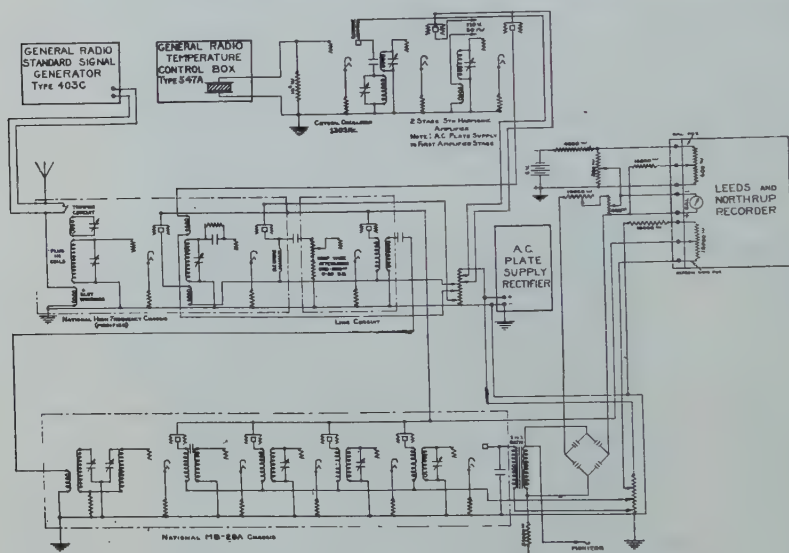


Fig. 8—Circuit diagram of high-frequency recorder.

able from February, 1926 to date. These funds were utilized in the earlier part of the series to pay for an observer for manual monitoring and later for the construction and maintenance of the recording apparatus described above and for the reduction of the records obtained.

The series soon proved its value in establishing significant correlations with certain cosmical elements⁶ and further investigations of this type are now in progress.

⁶ G. W. Pickard, "Correlation of radio reception with solar activity and terrestrial magnetism," 1 and 11, *Proc. I.R.E.*, **15**, 2; February, 1927; **15**, 9; September, 1927. "The relation of radio reception to sunspot position and area," *Proc. I.R.E.*, **15**, 12; December, 1927. "Some correlations of radio reception with atmospheric temperature and pressure," *Proc. I.R.E.*, **16**, 6; June, 1928. "Note on the fifteen-month period in solar activity, terrestrial magnetism, and radio reception," *Proc. I.R.E.*, **19**, 3; March, 1931. "A note on the relation of meteor showers and radio reception," *Proc. I.R.E.*, **19**, 7; July, 1931. "Notes on correlation-investigations between Kennelly-Heaviside layer and lunar altitude," *Trans. Am. Geophys. Union*, June, 1931.

III. FIELD INTENSITY FROM WEV (6942.5 KC)

During the past year a grant made available from the Permanent Science Fund administered by the American Academy of Sciences has made possible the construction of another recorder for investigation of field intensities in the high-frequency region. Many of the desirable features and circuit details employed in the broadcast frequency recorder have been retained but certain new problems accompanied the extension of the recording to include the higher frequency regions. Thus, the close frequency proximity of telegraph channels in the 7-megacycle region and the great variations of recordable signal intensity required extreme selectivity to be maintained and rendered the use of double detection and amplification at a lower intermediate frequency desirable. Inexpensive a-c operated high gain amplifiers of considerable selectivity were available in the broadcast frequency region already assembled in the form of broadcast receiving set chassis. This led to the choice of this frequency region for this amplification. In order to maintain the intermediate frequency within suitable limits, however, the use of a crystal controlled oscillator seemed desirable.

The intermediate frequency chosen (863.5 kc) required a local frequency of 7806 kc to be maintained with considerable stability, and a temperature controlled crystal was hence employed. However, as this frequency is rather high for direct crystal operation, a crystal of 1301-kc was employed, together with a sixth harmonic amplifier.

The circuit details for the set-up employed for this recorder including the two-stage crystal amplifier, are shown in Fig. 8, and the physical appearance of the apparatus is shown in Fig. 7. (It will be noted that many of the circuits employed in the broadcast recorder were retained in this case.) It was not considered desirable, however, to introduce still lower intermediate frequencies which would operate satisfactorily with the copper-oxide rectifier owing to the added complexity introduced by the additional crystal oscillator required and due also to annoyance from the increasing multiplicity of crystal harmonics (which are usually but imperfectly suppressed by convenient shielding) from other high gain receivers operating in close proximity. Another method was therefore employed to permit the use of a copper-oxide output circuit to the Leeds and Northrup recorder similar to that employed in the other recorders. In this case, this was accomplished by operating the first crystal harmonic amplifier plate supply from 110-volt a-c mains thereby introducing a large 60-cycle modulation on the local beat frequency (i.e., 7806 kc). This resulted in a 60-cycle modulation of the code signals received but (when introduced at this point) did not appreciably raise the inductive interference in the receiver or introduce a hum in the absence of signals.

The circuit details and operation of the recorder (as shown in Fig. 8) may, therefore, be briefly outlined as follows:

The incoming frequency (6942.5 kc) is first amplified by one stage of radio-frequency shield-grid amplification and then combined in a first detector tube with a modulated 7806-kc input supplied locally from the 1301-kc crystal oscillator and its associated sixth harmonic amplifier (with a 60-cycle modulation at the first stage's plate supply as already described). This modulated input is inductively coupled to the grid circuit of the shield-grid detector circuit. The radio-frequency amplifier and first detector were adapted from the assembly employed by the National Company in their high-frequency receiver, i.e., tuned circuits employing their standard 5-prong plug-in coils and ganged condensers (with tuner circuit) were utilized as assembled on their chassis. Appropriate circuit modifications were of course made as indicated. These coils are indicated in Fig. 8. The small winding indicated above and below the main winding are auxiliary windings of the slot type. These coils and condensers were also found convenient in the harmonic amplifier assembly as indicated.

The beat frequency output of the first detector plate circuit is resistance coupled to the grid of a "link-circuit" tube. The coupling resistance is in the form of a special logarithmic resistance which was wound to be as nearly as possible noninductive at broadcast frequencies and graduated in db. While such a crude attenuator (range 0-20 db) can hardly be expected to prove highly accurate it has in practice served as a convenient roughly metrical means of volume control. The anticipated calibration was found to check other calibrating means within about 30 per cent.

This link circuit was designed to permit the use of this type of coupling and to secure added selectivity rather than for additional gain (a slight gain is, however, realized in this stage). It also provides an appropriate input circuit to the broadcast chassis (utilized for intermediate frequency amplification) and thereby shows the full selectivity of the broadcast chassis preselector circuit to be utilized. A schematic diagram of the M B 29-A National chassis is shown. It will be noted that the input is directly to a tuned circuit rather than to an aperiodic tube as in the case of the later designs indicated in Fig. 6. If the broadcast chassis utilized here had employed an aperiodic tube (as in the case of the broadcast recorder) the use of a link circuit might have proved unnecessary as the input from the drop-wire attenuator could then have been introduced directly on the first grid of the broadcast chassis. Too great a loss of selectivity was however experienced if the preselector circuit was eliminated by introducing the slide-wire

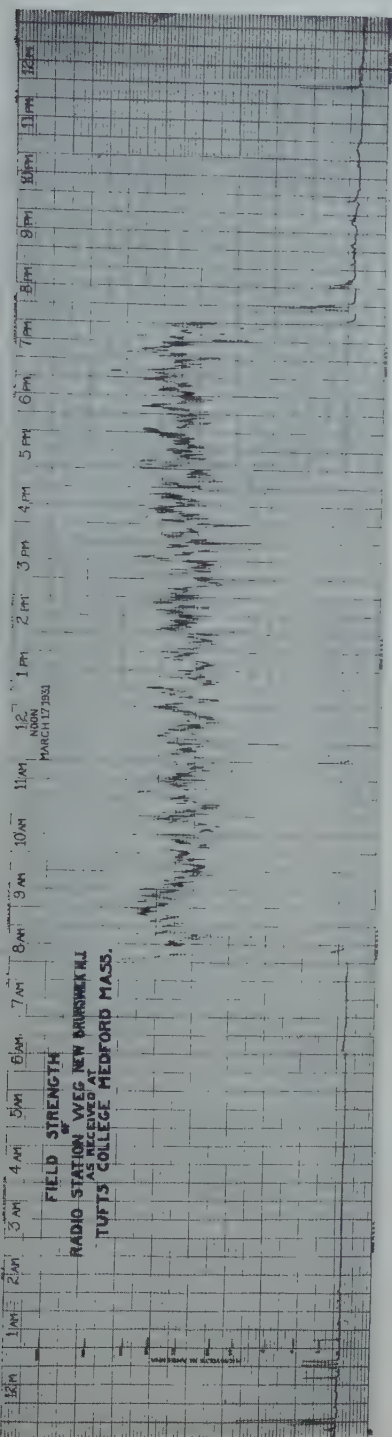


Fig. 9—Typical record obtained on WEG using high-frequency recording equipment.

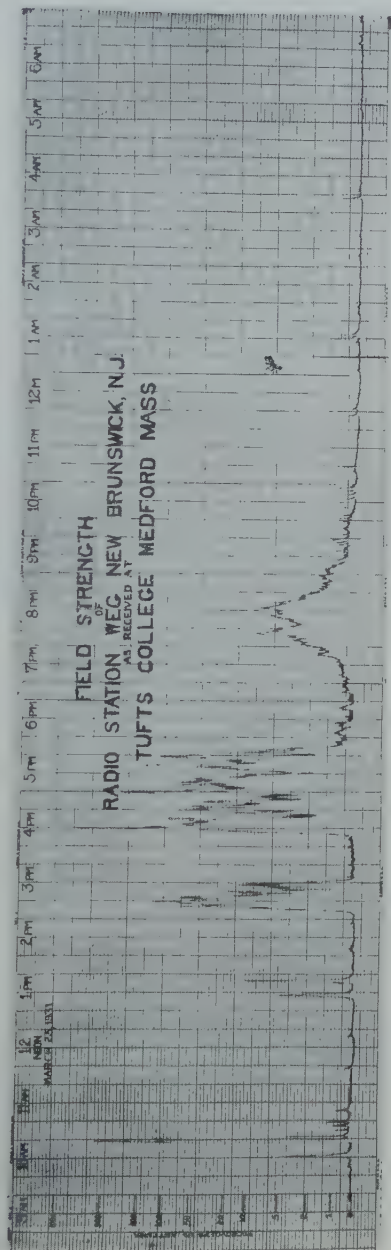


Fig. 10—Disturbed record obtained on WEG showing abnormally great fading.

attenuator's output voltage directly on the grid of the first tube of the broadcast chassis.

As in the case of the broadcast recorder shown in Fig. 6 a nearly logarithmic over-all characteristic is obtained for this recorder by use of a variable screen voltage in the intermediate-frequency (broadcast) amplifier. This voltage is controlled as in the case of the broadcast assembly, from a potentiometer carried on the same shaft as the Leeds and Northrup recorder potentiometer. The details of these circuits, and the input circuits to the recorder follow closely those already described and are shown in detail in Fig. 8. In this case of course the input to the copper-oxide rectifier is the 60-cycle component in the second detector circuit resulting from the detection of the modulated intermediate frequency code signal input produced as already described.

During the spring of 1931 observations were made on station WEG on 7415 kc. Changes in operating schedules, etc., however, rendered a change to WEV on 6942.5 kc necessary during the summer of 1931 between the time this paper was presented at the U.R.S.I. meeting in April, 1931, and the time of its publication.

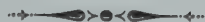
The phenomena observed on both frequencies are nearly identical (since the transmission path is the same and the frequencies not very different) and the results obtained during the earlier series of observations on WEG will hence be described (as in the oral presentation).

For recording WEG an intermediate beat frequency of 6505, i.e., fifth harmonic, was used. This gave a beat frequency of 910 kc.

A typical WEG record on which the resulting scale obtained is noted is shown in Fig. 9. This scale is calibrated in microvolts in the antenna by means of the General Radio standard signal generator which is adapted by plug-in coils to operate in this frequency region. Certain further precautions are required, however, to secure a reliable calibration at this frequency. Thus, additional shielding with a *one-point* ground was required and it was found desirable to locate the generator at about 6 feet from the apparatus and to utilize shielded input leads.

The typical record shown in Figs. 9 and 10 admirably emphasises the enormous changes in field from day to night produced by skip-distance phenomena. The WEG transmitter operates on a 24-hour schedule on a nondirectional antenna system, and through kind co-operation with the R.C.A. added precautions were taken to insure the continuity of the transmission during periods of light traffic. The enormous and very rapid changes in field intensity due to Kennelly-Heaviside layer height variations, etc., are therefore without doubt

genuine. Marked seasonal changes and correlations with magnetic phenomena are anticipated as soon as a sufficiently long series of data has accumulated to make statistical treatment appropriate. A more detailed consideration of these records will be considered in another paper.



THE PROPAGATION OF SHORT RADIO WAVES OVER THE NORTH ATLANTIC*

By

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Summary—Transmission conditions for each season are shown by "surfaces" giving the received field strength as a function of time of day and frequency. These show that frequencies near 18 mc are best for daytime transmission. In summer the best frequencies for nighttime transmission are those near 9 mc. In winter an additional frequency near 6 mc is required during the middle of the night. A frequency (such as 14 mc) intermediate between the day and night frequency is useful during the transition period between total daylight and total darkness over the path. Day-to-day variations change the periods of usefulness of these frequencies. In particular the period of usefulness on 14 mc sometimes extends so that it is the best daytime frequency.

Transmission conditions on undisturbed days were found to be the same for the same time of year on different years. These undisturbed transmission conditions are presented by "normal" surfaces. Comparison of these surfaces shows that the higher frequencies are less attenuated in winter. Reception on the highest frequency, 27 mc was best in winter; in summer this frequency was never heard.

The effect of solar disturbances on short-wave transmission is to reduce reception on all frequencies. Sometimes the higher frequencies are the more adversely affected. Some of the possible causes of these disturbances are discussed.

From the measurements made on "static" at New Southgate, data on the variation of its field strength as a function of frequency, time of day, and season are given.

INTRODUCTION

FROM the point of view of actual or potential commercial development, there probably is no radio communication area that can exceed the North Atlantic in importance. This applies not only to the point-to-point links connecting this continent with the populous countries of Europe, but also to the growing services to ships which travel this most important sea route. A complete picture of the high-frequency (short-wave) radio transmission characteristics of this path is naturally of great interest but it is apparent that a comprehensive view will require observations over a period of years. While the more general characteristics of transmission are reproduced year after year, important differences also occur. We cannot be entirely certain that our picture is correct, even in a qualitative sense, without consistent observations over a long period.

This paper, therefore, is presented as a contribution toward this more comprehensive body of data bearing on transatlantic transmis-

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sion. It gives quantitative measurements of the field strength from Deal, N. J., as measured at New Southgate, England, from June, 1926 to August, 1929.

SCOPE

Transmissions were made in rotation on several frequencies which covered the useful range for this path. For the greater part of the time transmissions were made throughout the twenty-four hours at intervals of one week. On each frequency the test consisted of an identification signal, unmodulated carrier, steady tone modulation, and intelligibility test. At the receiver the field strength was measured, and the type and intensity of fading were noted. The field strength of "static" was measured on each frequency during a silence period immediately after transmission on that frequency.

One of the short-wave transmitters¹ of the Bell Telephone Laboratories at Deal was employed for these tests. It consisted of a crystal controlled master oscillator with two stages of power amplification subsequent to modulation. The standard radiators for these tests were inductively loaded half-wave vertical antennas. At various times, however, simple directive antennas were used. In these cases the field strength results were corrected by the use of a factor which was found by actual experiment to represent the relative efficiencies of the two antennas in the direction of England.

The receiver was a double detection measuring set. For some of the early tests a field strength recorder² designed by R. A. Heising was employed. During June, 1926, and since December, 1926, a measuring set of greater sensitivity, developed by H. T. Friis and E. Bruce,³ was used.

The field strength data for individual days have been plotted as shown in Fig. 1.⁴ Each circle gives the average field strength received during the five-minute tone period, in decibels above one microvolt per meter for one kilowatt radiated from a half-wave vertical antenna. The solid lines connect measured values and the dashed lines estimated values. These estimated values were obtained by producing a beat note with the incoming signal and comparing this beat note with a locally produced beat note. This local beat note had a definite relation to the

¹ For description of transmitter see R. A. Heising, J. C. Schelleng, and G. C. Southworth, "Some measurements of short-wave transmission," *Proc. I.R.E.*, **14**, 614-615; October, 1926; E. B. Ferrell, "The transatlantic short-wave transmitters," *Bell Laboratories Record*, **7**, 497-501; August, 1929.

² For photograph see *Proc. I.R.E.*, **14**, 617, 1926.

³ "A radio field-strength measuring system for frequencies up to forty megacycles," *Proc. I.R.E.*, **14**, 507-519; August, 1926.

⁴ The curves for individual days have been omitted for clarity and to bring the scope of the paper within reasonable limits.

lowest measurable signal so that the method gave the field strength with a fair degree of accuracy. The lowest audible signal is indicated by the narrow dashed line. This gives an upper limit to the signal

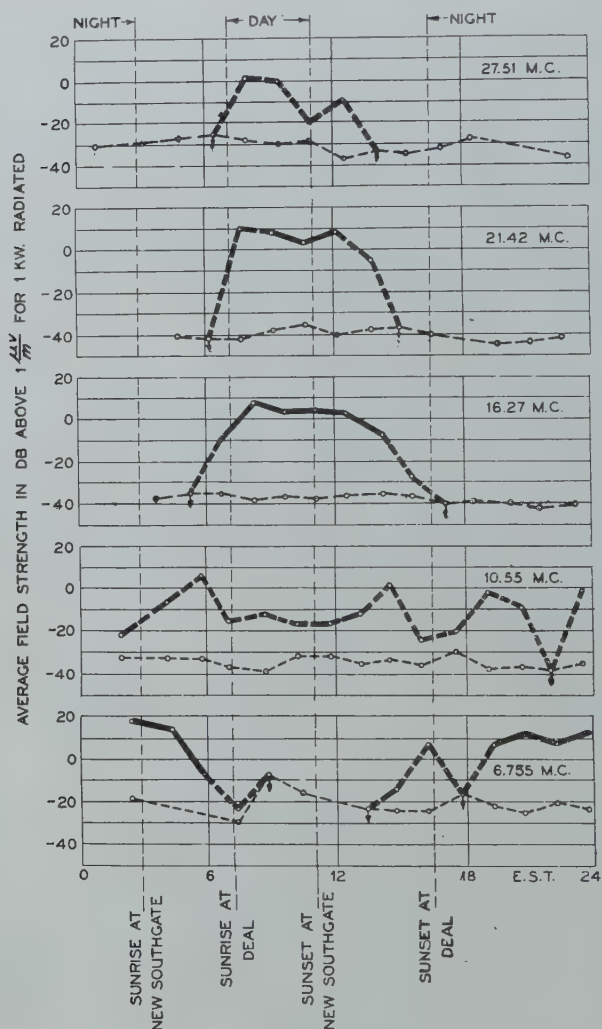


Fig. 1—Diurnal variation of received field strength on December 14, 1928.

strength when the signal was not heard. An arrow pointing down from a circle indicates that the signal was below this value.

These diurnal variation curves of the received field strength are typical of transmission over the path in winter on undisturbed days.

Transmission conditions change with the time of year and condition of the sun as well as with time of day as shown by the curves.

In order to show the variation with time of year, average transmission conditions for each season were obtained by grouping the data into four seasonal periods such that the middle of each quarter was a solstice or an equinox. Curves showing the average diurnal variation

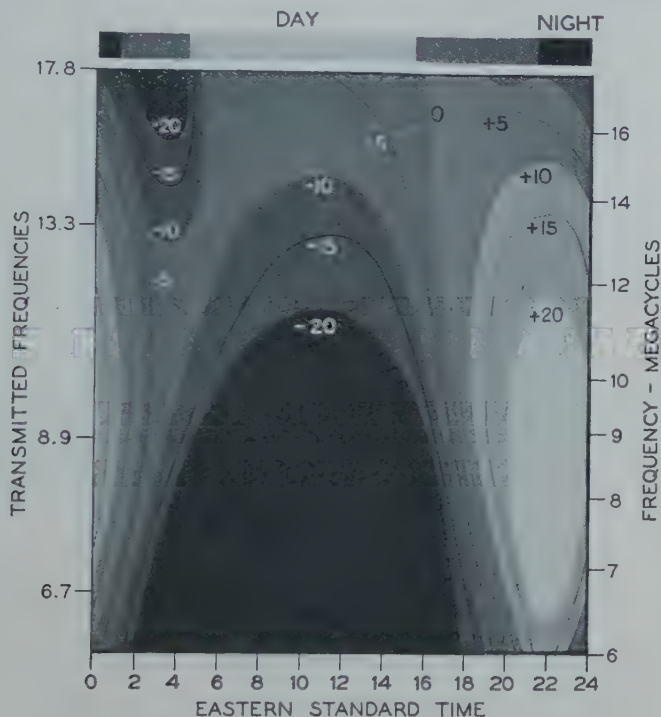


Fig. 2—Average field strength surface for June, 1926.
Db above $1 \mu\text{V}/\text{m}$ for 1 kw radiated.

of the received signal on each frequency were drawn. From these, curves have been drawn in which the field strength is given by contours on a coordinate system with time of day as abscissa and frequency as ordinate.

AVERAGE TRANSMISSION CONDITIONS

These field strength "surfaces" (Figs. 2 to 12) show at a glance the average transmission characteristics on frequencies within the useful range for this path. They all have certain characteristics in common. These are (1) the nighttime peak or plateau for the lower frequencies, (2) the more or less level region during the daytime on the higher fre-

quencies, (3) the early morning valley on the higher frequencies, due to the skip effect, (4) the valley at the lower frequencies in the daytime, due to absorption caused by excessive ionization, and (5) the "saddle" connecting (1) and (2), and separating (3) and (4).

The character of these features changes gradually with the seasons. The nighttime maximum (1) and the nighttime minimum (3) widen as

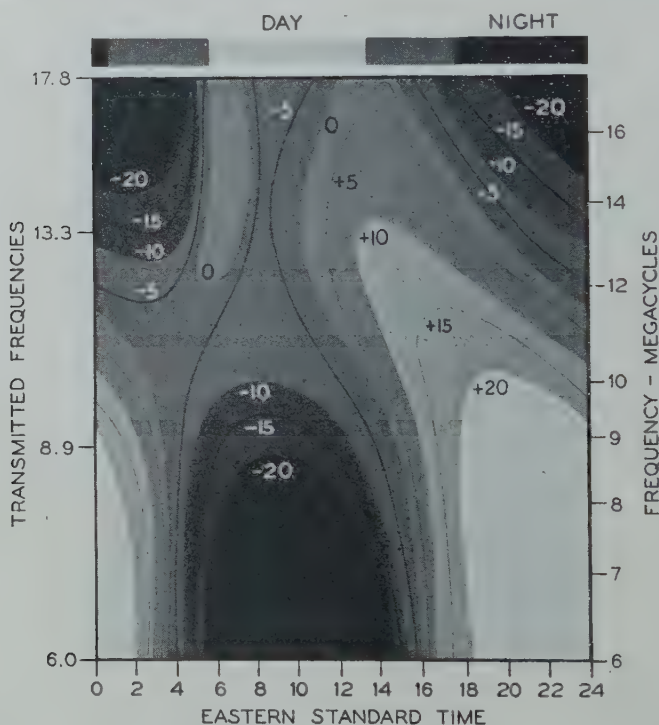


Fig. 3—Average field strength surface for autumn, 1926.
Db above 1 $\mu\text{V/m}$ for 1 kw radiated.

the season changes from summer to winter. On the other hand the daytime features, (2) and (4), become narrower in accordance with the length of day and night.

These figures show transmission conditions near a sun spot maximum. They probably are representative of transmission conditions over this path in general, although this is not necessarily true of the details.

The reader who is not interested in the detailed discussion of these surfaces is referred to the next section on "Normal Transmission Conditions," page (1643).

Fig. 2 represents data taken on ten consecutive days in the month of June, 1926. These were the transmission conditions at the summer solstice. The early morning minimum was extremely short. This is presumably due to the fact that in summer darkness over this particular transmission path does not extend very high above the surface of the earth at any time during the night.⁵ The short period of total darkness

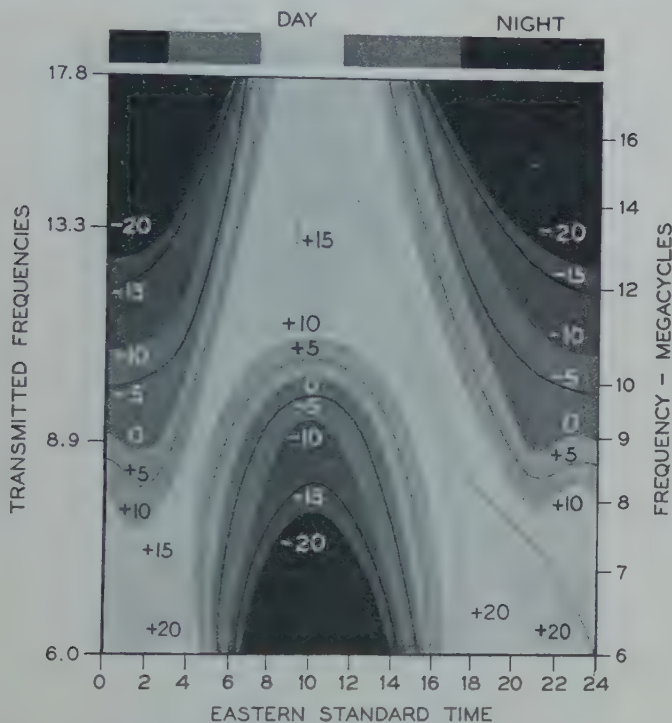


Fig. 4—Average field strength surface for winter, 1926-1927.
Db above 1 $\mu\text{V}/\text{m}$ for 1 kw radiated.

also results in a large daytime absorption valley. These depressions go below the limit of sensitivity of the receiver. The field strength was probably very much lower than minus twenty decibels within the black regions.

The maximum field strength occurred in a region around 9 mc at 2200 E.S.T. (10 P.M.). Although the field strength was lower on 18 mc, it was sufficient for telephony during almost the entire twenty-four

⁵ Due to the high latitude twilight extends throughout the night during this month for over half of the transmission path. Since points a few degrees further north have daylight throughout the twenty-four hours at this time, the zenith distance to the edge of the earth's shadow is small.

hours. This was due in part to the lower noise level on the higher frequencies.

As the season progressed to autumn (Fig. 3) there was an apparent shift of similar transmission conditions to lower frequencies. The plateau on the lower frequencies was broader and extended to even lower frequencies than those measured. Transmission during the daytime was

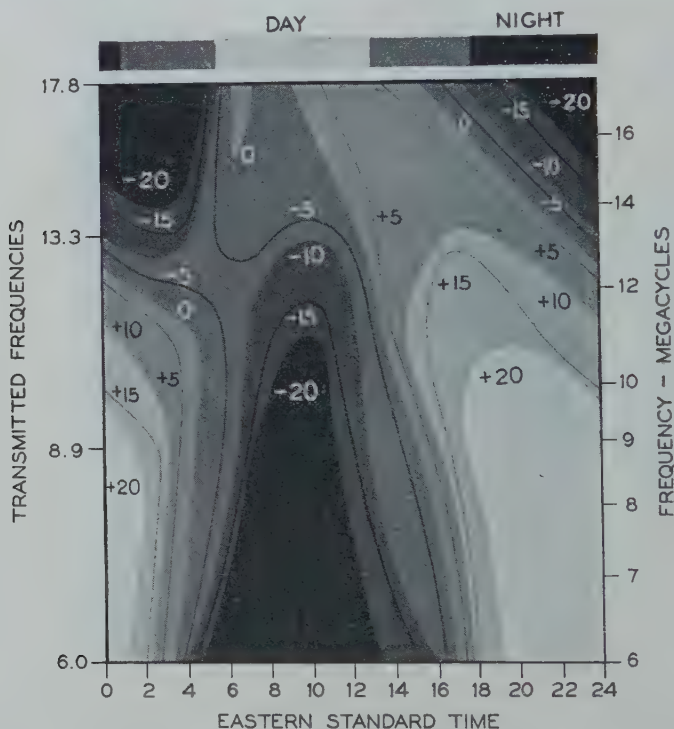


Fig. 5—Average field strength surface for spring, 1927.
Db above 1 $\mu\text{V}/\text{m}$ for 1 kw radiated.

also possible on lower frequencies. The skip valley was larger, the absorption valley smaller.

The same changes are noticed in going from the autumn to the winter quarter (Fig. 4). Here the highest field strength probably occurred on a frequency below the lowest frequency transmitted. The spring quarter of the next year (Fig. 5) was similar to that of the previous autumn.

A higher frequency was included in the tests the next year. Fig. 6, for summer, 1927, is not directly comparable with Fig. 2, the data for which was limited to the month of June, 1926. The fact that the latter

represents conditions at the solstice rather than for the whole three-month period, is partial explanation of the differences shown. It will also be observed that the maximum frequency used was greater in 1927.

Transmission conditions during autumn and winter were not as favorable in 1927 as in 1926. The general level of the field strengths was

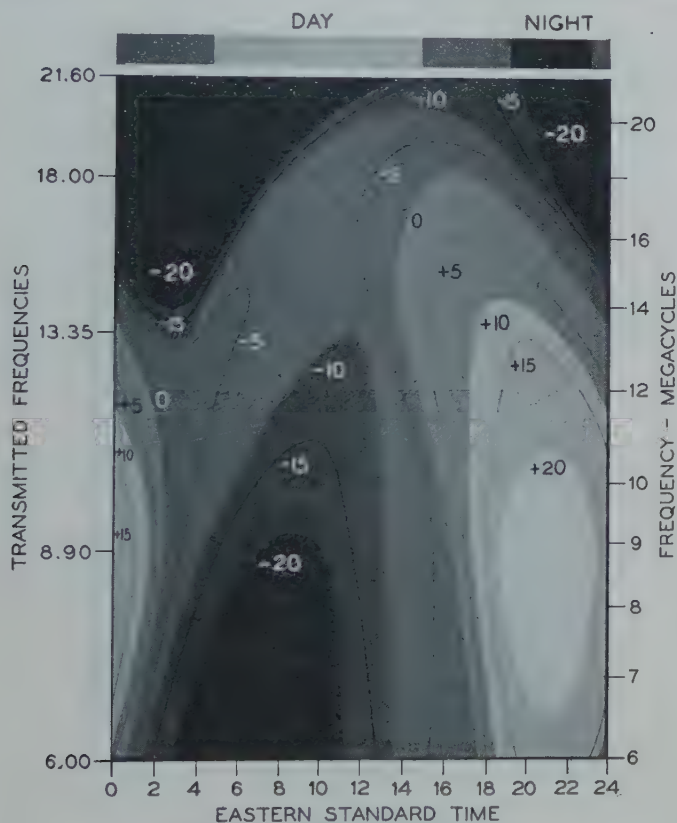


Fig. 6—Average field strength surface for summer, 1927.
Db above $1 \mu\text{v/m}$ for 1 kw radiated.

more than 10 db below those of the previous year as can be seen by a comparison of Fig. 7 with Fig. 3, and Fig. 8 with Fig. 4. By the spring of 1928 the field strengths had increased and were above those of the previous year. (Compare Figs. 5 and 9.)

The differences between surfaces for the same season for two years are probably due to a difference in the ratio of the number of disturbed days to the number of undisturbed days included in the averages for

the two years. As will be shown later, the average transmission conditions on undisturbed days were the same for the same time of year on different years. The differences, then, are due to the disturbed days that are included in these seasonal averages.

The surface for winter, 1928-1929,⁶ (Fig. 10) is similar to those of the two previous winters. The general level at the lower frequencies has

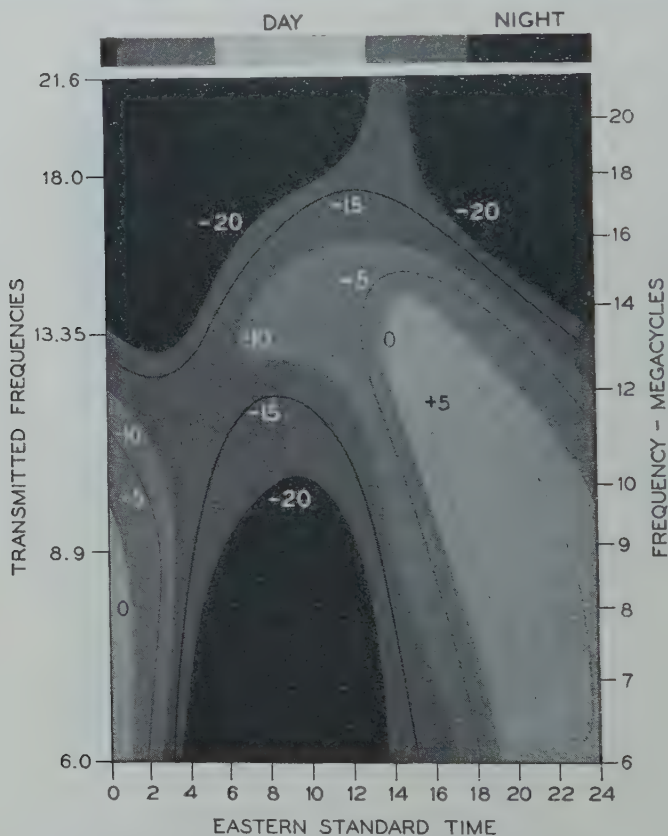


Fig. 7—Average field strength surface for autumn, 1927.
Db above $1 \mu\text{v/m}$ for 1 kw radiated.

recovered to that of 1926-27 while the higher frequencies tend to hold the 1927-1928 values. The higher frequency, 27 mc, which was included this quarter, was received only during the period of total daylight. In the following spring (Fig. 11) reception on this frequency was reduced, and in the summer (Fig. 12) this frequency was never received.

⁶ These tests were temporarily discontinued during summer and autumn, 1928.

From these surfaces it is evident that there is a seasonal variation in transmission characteristics depending upon the "exposure" of the path to the sun. Besides these "normal" variations there are other seemingly haphazard variations due mainly to solar disturbances. It is as if the normal variations were modulated by changes in solar activity giving the complicated results observed.

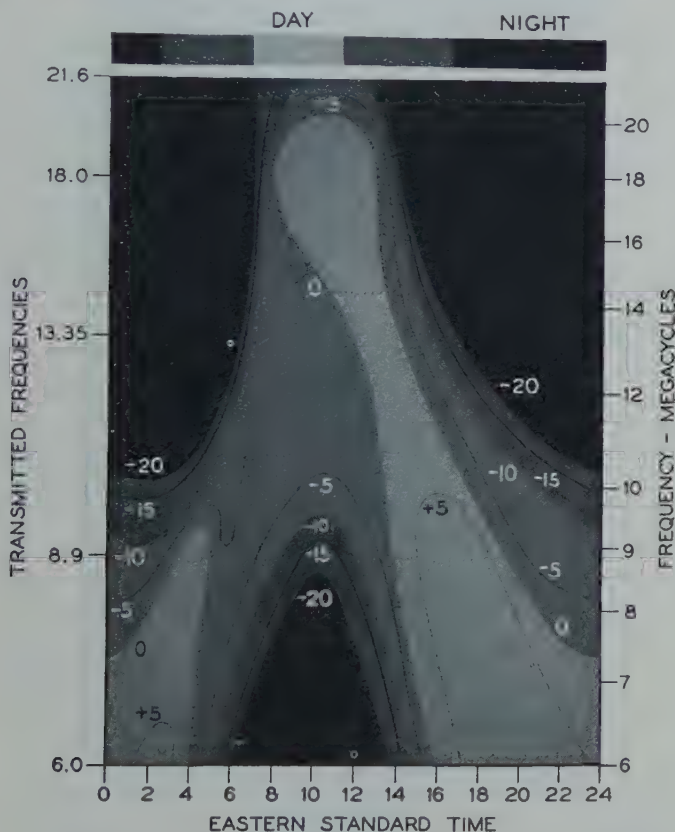


Fig. 8—Average field strength surface for winter, 1927-1928.
Db above $1 \mu\text{v}/\text{m}$ for 1 kw radiated.

"NORMAL" TRANSMISSION CONDITIONS

We must naturally be cautious in using the word "normal." It is not unlikely that variations are the normal thing to expect. This view is strengthened by the corresponding conclusion in terrestrial magnetism. In northern latitudes the earth's magnetic field is "normally" in a stage of disturbance, the fluctuations increasing as the auroral region is approached.⁷

Nevertheless, for transatlantic transmission there are a large number of days showing practically undisturbed conditions which are properly regarded as "normal." Average transmission conditions on these days are shown in Figs. 13 and 14 for summer and winter respectively. In selecting the normal days, those that showed a large variation from the remainder were discarded, as in selecting average data in

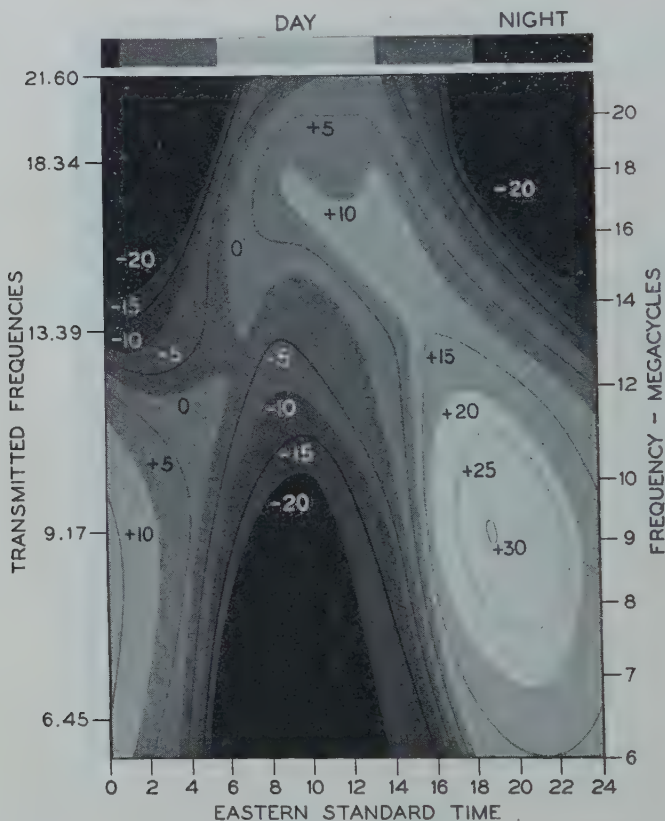


Fig. 9—Average field strength surface for spring, 1928.
Db above 1 $\mu\text{V}/\text{m}$ for 1 kw radiated.

precise experimental determinations. The occurrence of magnetic storms and the passage of large spots across the central meridian of the sun were used as guides in discarding "disturbed" days.

These figures (13 and 14) show the normal transmission conditions over this transatlantic path during the last sun spot maximum. Trans-

⁷ S. Chapman, "On certain characteristics of world wide magnetic disturbances," *Proc. Roy. Soc. (London)*, A115, 254; July, 1927.

mission conditions on normal days probably do not change very much from year to year although there is a possibility that the ionization of the upper atmosphere may be different during a period of maximum solar activity even on magnetically "quiet" days.

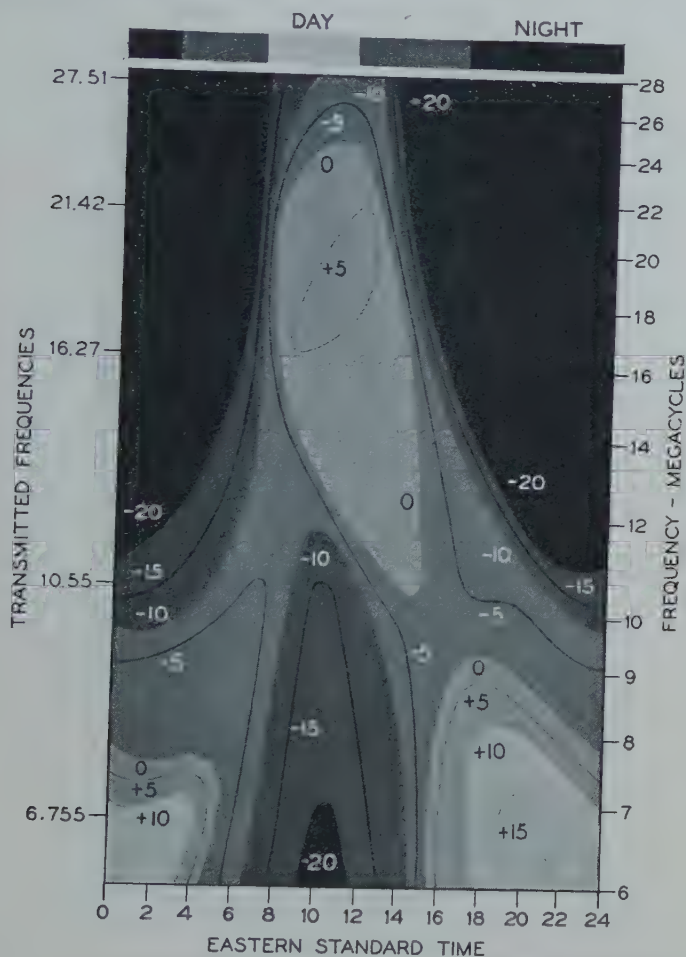


Fig. 10—Average field strength surface for winter, 1928-1929.
Db above $1 \mu\text{V/m}$ for 1 kw radiated.

The fact, found by C. Chree,⁸ that the diurnal variation of the earth's magnetic field on quiet days is different during a period of maximum solar activity than that during a period of minimum activity indicates that a similar difference is to be expected in normal radio transmission.

⁸ Studies in Terrestrial Magnetism, pages 160-176.

Fig. 13 represents normal transmission conditions over the path during summer with a fair degree of certainty. The diurnal field strength variation curves for the individual years are very similar in shape (see Fig. 15),⁹ indicating that truly undisturbed days were used in the

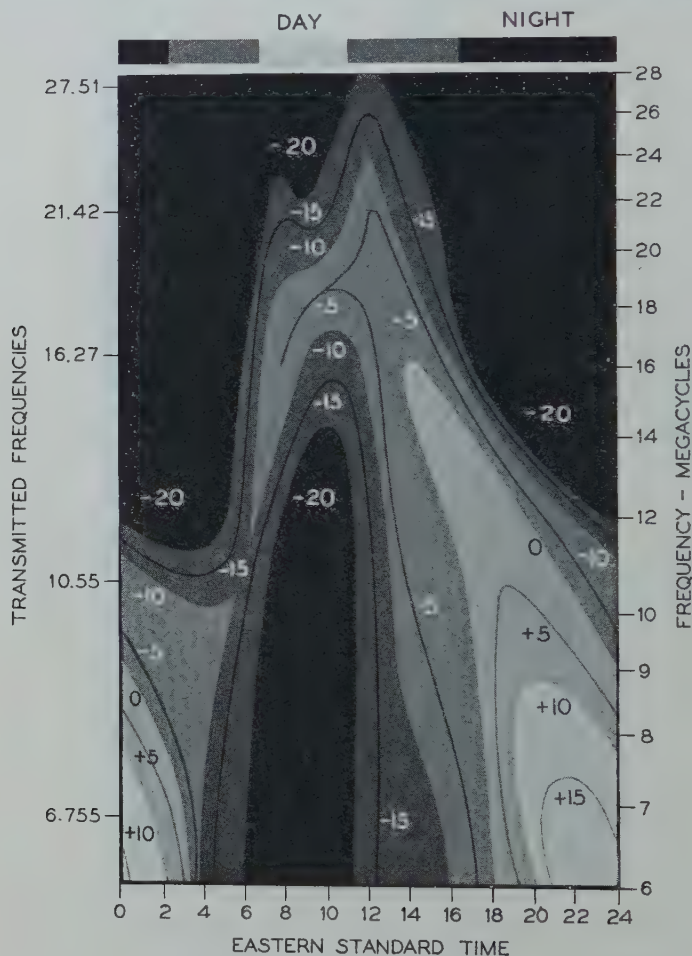


Fig. 11—Average field strength surface for spring, 1929.
Db above $1 \mu\text{v/m}$ for 1 kw radiated.

averages. Also the diurnal field strength variation curves for the different frequencies fit together to make a smooth surface (see Fig. 15),

⁹ The spread between the curves for different years at the lower values of field strengths indicates a change in the sensitivity of the measuring system (transmitted power, antennas, receiver, etc.) rather than a difference between the years.

indicating that data were obtained on frequencies close enough together to show the characteristics throughout the frequency spectrum explored.

This normal surface is very similar to the average summer surface for the individual years. The skip minimum that occurs during the

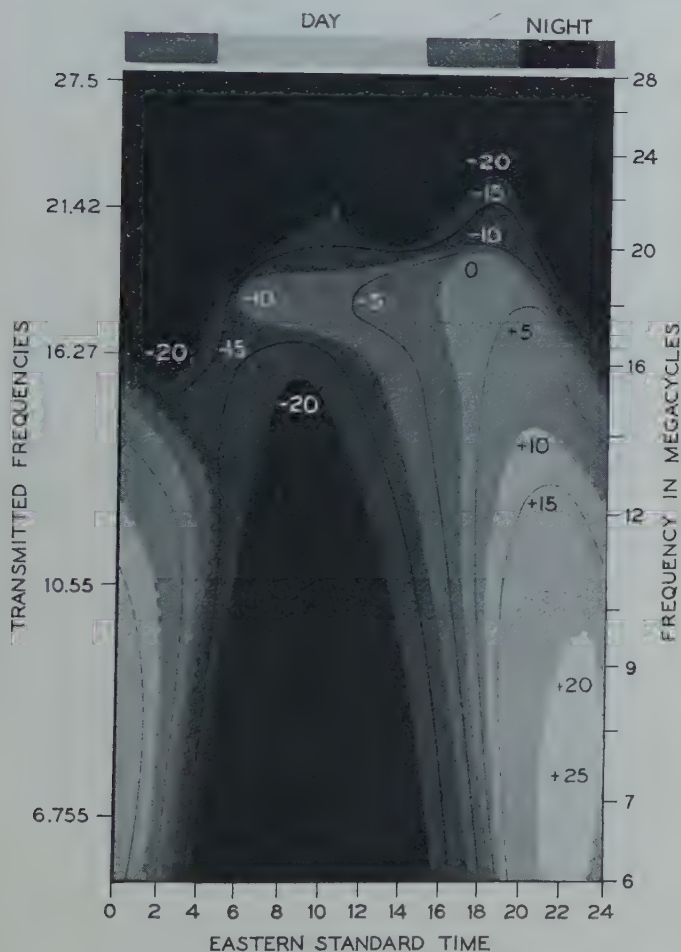


Fig. 12—Average field strength surface for summer, 1929.
Db above $1 \mu\text{v/m}$ for 1 kw radiated.

light on frequencies near 18 mc spreads out as the frequency is increased until it extends throughout the 24 hours on frequencies slightly higher than 22 mc. On normal days frequencies near to 18 mc are the best for daytime transmission.¹⁰ Frequencies in the neighborhood of 9

mc have the highest fields during the night. A transition frequency might not be necessary on the afternoon of normal summer days since the times of high fields on 18 and 9 mc overlap. In the early morning, however, a transition frequency of 14 mc should be useful. The daytime

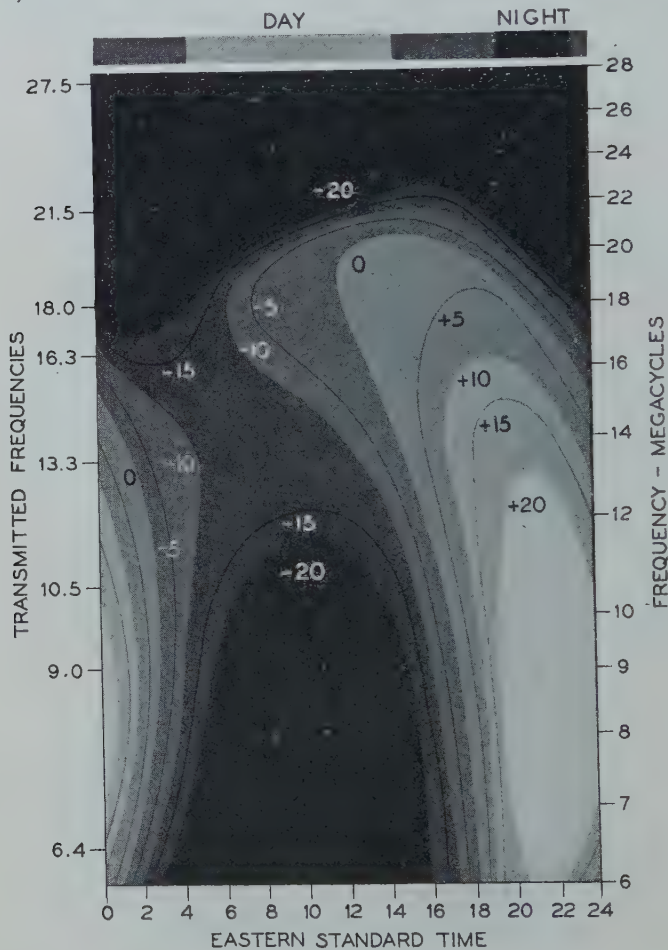


Fig. 13—Normal summer field strength surface.
Db above 1 $\mu\text{V}/\text{m}$ for 1 kw radiated.

absorption minimum is pronounced on frequencies lower than 13 mc.

While the normal winter surface, Fig. 14, represents the major characteristics of transmission over the path on normal winter days, the

¹⁰ Here and elsewhere throughout the paper comparisons between frequencies refer to received field strengths. In the operation of a telephone circuit there are other important factors, such as, noise, fading, and interference that are beyond the scope of this paper.

details are somewhat in doubt. Although the diurnal variation curves for 1926-1927 and 1928-1929 are very much the same for the two frequencies on which tests were made both years, namely 18.4 and 6.7 mc, the field strengths were lower during 1927-1928 on all of the test frequencies. This difference is especially marked on the higher frequencies.

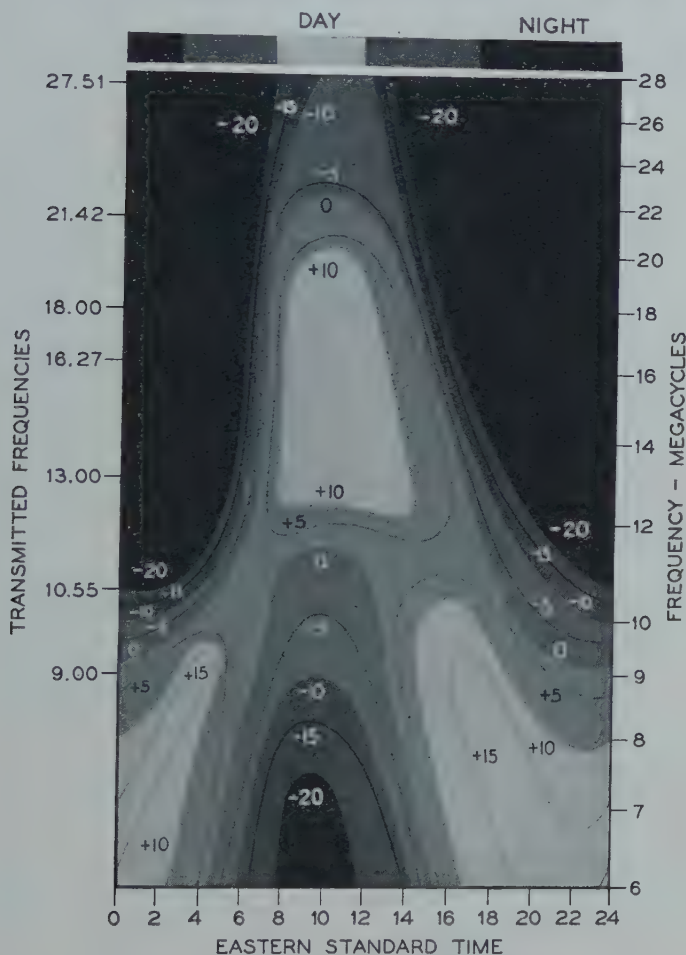


Fig. 14—Normal winter field strength surface.
Db above 1 $\mu\text{V}/\text{m}$ for 1 kw radiated.

cies, 21.6, 18.4, and 13.4 mc. Only three of the test days were picked as "normal" during 1927-1928, and since the field strength was reduced on these days there probably was an after effect of disturbed conditions even on these days.

The field strengths on the two new frequencies, 16.27 and 10.5 mc, included during 1928-1929, were lower than the smooth surface through the remainder of the data would indicate. In view of the fact that the fields on the other frequencies were not reduced that year, it seems to indicate that transmission conditions were more unfavorable for these frequencies than for the test frequencies on either side of them. Since this has no simple physical explanation and the data on the adjacent test frequencies were obtained in a different year, it has been assumed that the data is insufficient to determine these details of the surface, and smooth curves showing the average conditions have been drawn through the data.

The normal winter surface, Fig. 14, has the same general characteristics as the average winter surfaces for the individual years, but the general level is slightly higher. This figure indicates that during the period of total daylight, transmission on the higher frequencies is better in winter than in summer. In summer the surface goes below the -20-db level at about 23 mc while in winter it is still above -10 db at 28 mc.¹¹ This is remarkable since the other three regions are affected in an opposite direction.

The nighttime skip region is much more pronounced in winter. In summer it is only a small tongue extending about 5 mc below the high-frequency limit of the surface to about 17 mc, while in winter it extends over 18 mc, from beyond the frequency range explored to about 10 mc.

The daytime absorption on the lower frequencies is less in winter, which causes this valley to be partly filled in, so that it has the same height at 8 mc for winter that it has at 13 mc for summer. In fact, normal transmission conditions during the period of total daylight are more favorable in winter on all frequencies. The field strength on the best day frequency is about 10 db above the summer maximum, and the surface extends more than 6 mc further into the higher frequencies and about 4 mc further into the lower frequencies.

While transmission conditions during the daytime are satisfactory on 18 mc in winter as well as in summer, they are also satisfactory on lower frequencies. In fact, the period of high fields in winter is

¹¹ It would be desirable to have more data on this point since the frequency of 27 mc was transmitted during only one summer and one winter. On this basis alone it would probably be unsafe to conclude that the difference was a seasonal effect. However, if the difference is due to some other cause than a seasonal one, it should be evident also on 18 mc where we have data covering a period of years. On 18 mc the differences between these two periods, other than the seasonal variations, are much smaller than the differences on 27 mc indicating that this is a seasonal variation. Also the monthly averages of the daytime field strengths on 18 mc have a minimum in summer and a maximum in winter indicating a better transmission of the higher frequencies in winter.

longer on 13 mc than on 18 mc. The higher frequency may still be desirable for daytime transmission, however, due to the fact that the atmospheric noise is lower on this frequency or for other reasons. The lower frequency (13 mc) then becomes necessary as a transition frequency between daytime and nighttime conditions.

The best nighttime frequencies are lower in winter than in summer. The skip valley extends so far into the low frequencies that a frequency below 9 mc is required for transmission during the middle of the night. This and the absorption valley extend so far into the intermediate frequencies that the plateau is divided into three parts.

Day-to-day variations are great enough to change the best frequency. Due to the difficulty of maintaining short-wave telephone communication over this path, it is desirable to determine the best frequency experimentally each day. Since transmission conditions gradually change from day to night, this means that as transmission conditions on one frequency become poor the next lower frequency is brought into service. The operation is repeated in the reverse direction in going from night to day. Disturbed conditions require a different choice of frequencies. This will be discussed later.

DISCUSSION

All of the main differences between the normal summer and the normal winter surfaces can be explained by the fact that the transmission path is more exposed to the ionizing effect of ultra-violet radiation from the sun during summer than winter.

There are two ways in which the ionization of the upper atmosphere may cause a "skip effect." The ionization may not be sufficient to cause the necessary refraction, or the ionic gradient and atmospheric density may combine to produce excessive absorption. Regardless of which of these effects predominates, the *nighttime* "skip" region should be of longer duration in winter than in summer because of the corresponding length of night.

Other things being equal, the absorption on all frequencies should be less in winter because of the lesser ionization at the lower altitudes. On the lower frequencies this results in a smaller daytime absorption region. As the frequency is increased, the received signal strength should also increase until a frequency is reached where some other effect predominates. This results in the field strengths on 12 to 20 megacycles being larger in winter than in summer.

The fact that the field strength is lower in the summer than in winter on frequencies above 20 megacycles, can hardly be explained on the simple hypothesis of insufficient ionization as the cause of the "skip"

effect since the summer maximum should then exceed that of winter. It is apparently necessary to bring in absorption in order to explain the difference between the two surfaces. It may well be that for this region of the surfaces, the wave never penetrates to the region of maximum ionization. If this be so, then the fact that at noon better transmission is obtained during winter than during summer may be explained for all frequencies by the same assumption, namely that the ionization which

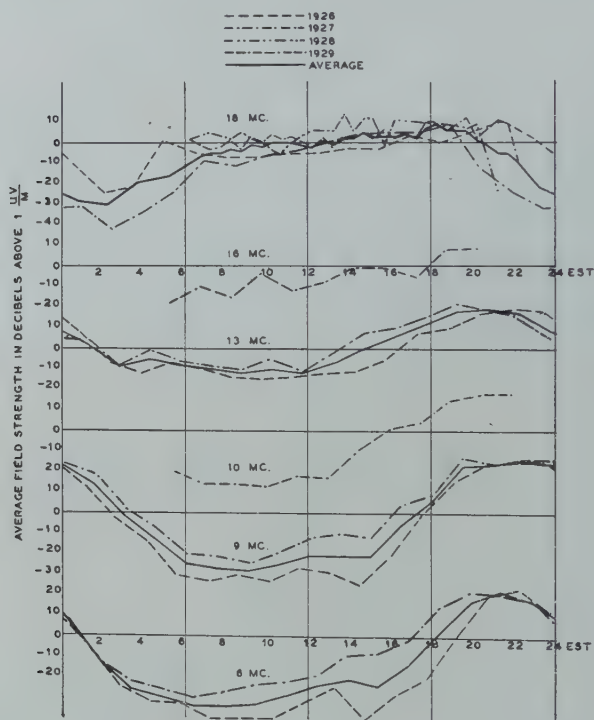


Fig. 15—Diurnal variation of received field strength on normal days in summer.

is necessary to produce refraction occurs in winter at levels where the air density is less than it is in summer. In the summer the maximum frequency at which a signal can be received over this path is about 23 mc. If it is proper to refer to this absence of signals at the higher frequencies as a "skip effect," then the explanation of this "skip effect" in the theory held by T. L. Eckersley¹² appears to be correct.¹¹

¹¹ *Loc. cit.*

¹² "Short wave wireless telegraphy," *Jour. I.E.E.* (London), **65**, 600-644; June, 1927; "An investigation of short waves," *Jour. I.E.E.* (London), **67**, 1027-1029; August, 1929.

DISTURBED TRANSMISSION CONDITIONS

The effect of solar disturbances is always to reduce the received field strength¹³ below the normal values for all frequencies. Of especial interest is the fact that the optimum frequency is often shifted to a

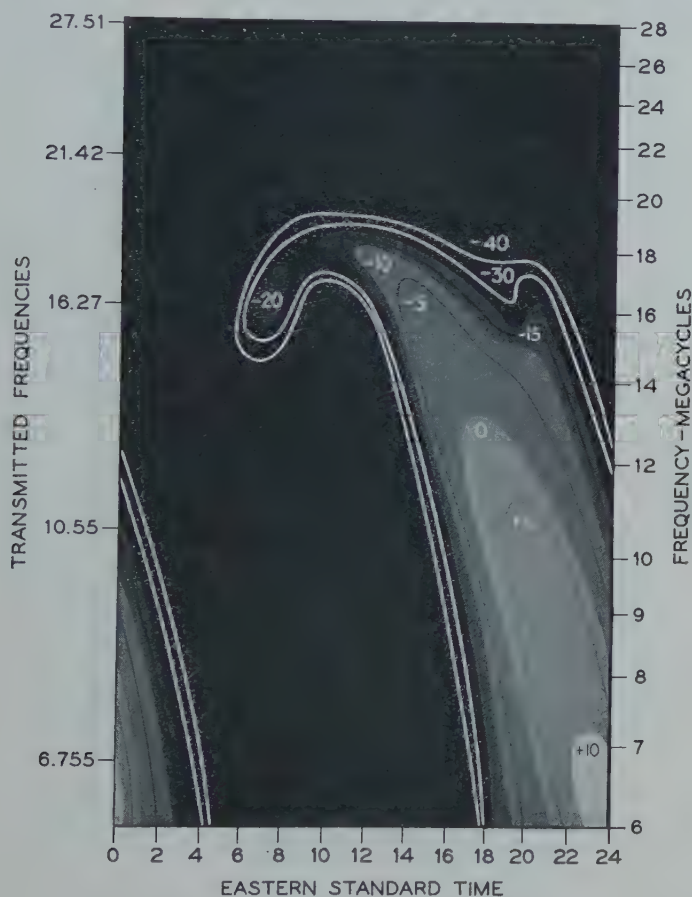


Fig. 16—Field strength surface for March 1, 1929.
Db above $1 \mu\text{v/m}$ for 1 kw radiated.

lower value. In fact, the whole surface is sometimes shifted toward the lower frequencies. The general reduction in field strength at these times makes the selection of the best frequency especially important. An

¹³ C. N. Anderson, "Notes on the effect of disturbances on transatlantic radio transmission," *Proc. I.R.E.*, 17, 1528-1535; September, 1929; W. Wilson and L. Espenschied, "Overseas radio extensions to wire telephone networks," *Proc. I.R.E.*, 19, 282-303; February, 1931.

intermediate frequency, such as 14 mc, therefore, finds considerable application at these times. As pointed out previously, this frequency is also useful at some times of year during the transition between day and night.

An example of disturbed radio conditions is shown in Fig. 16. This

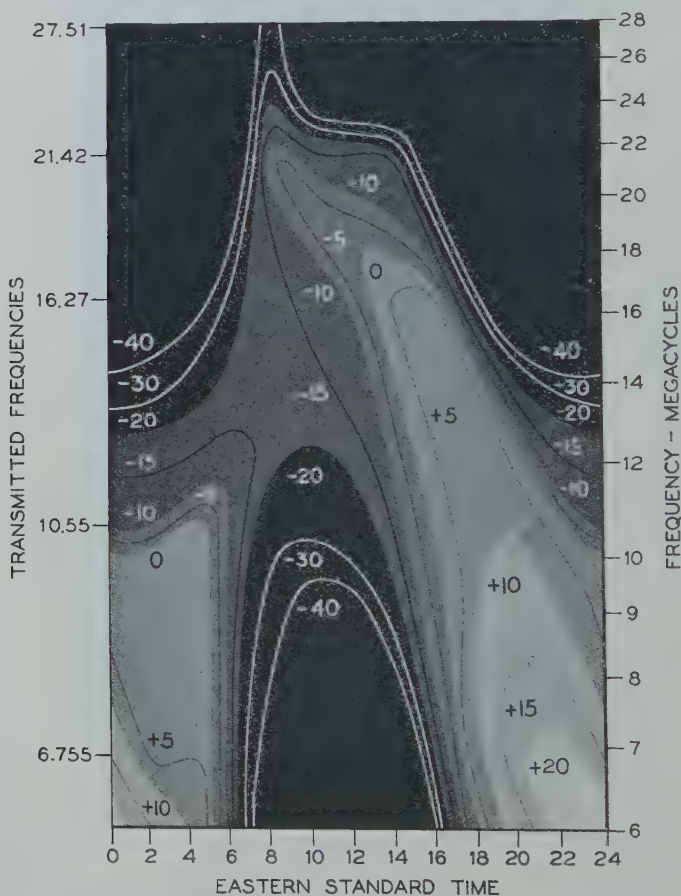


Fig. 17—Field strength surface for February 21, 1929.
Db above $1 \mu\text{v/m}$ for 1 kw radiated.

gives transmission conditions on the day after the most disturbed day. The nature of the disturbance can be seen by comparison with Fig. 17 which represents conditions on a normal day. The general level of the received field strength is lowered resulting in a union of the absorption and skip valleys.

In the discussion of normal conditions, it was observed that the general signal level is higher in winter than in summer during the day-time. In other words the lower signal level is coincident with the stronger ionization. Extending this rule to include disturbed days, it is possibly not improper to conclude that the still lower signals then observed are due to a still stronger ionization. This, in fact, is the view usually held. It is of some interest, however, to note that these two experimental observations are consistent with that view.

It is generally recognized that "magnetic storms," earth current "storms," aurora, and the disturbed radio transmission conditions that accompany them have their origin in the sun. The exact nature of the solar disturbance that is responsible for the disturbed terrestrial conditions, and the nature of the emanation from the sun by which these disturbances are transmitted to the earth have not been determined experimentally. One theory suggested by A. Schuster¹⁴ and developed by H. B. Maris and E. O. Hulburt,¹⁵ assumes the emanation to be ultra-violet light. This theory postulates a flash of ultra-violet light such as would come from a hot spot 10^{-4} of the solar disk in size and at a temperature of 30,000 degrees K. Such a flash would result in a brightening of the sun in the visible spectrum equivalent to a change of 5 in stellar magnitude. That is, the spot would appear as much brighter than the sun's disk as a first magnitude star is brighter than the faintest star which is visible with the naked eye.

The only known observation of such a spot was made by R. C. Carrington¹⁶ and R. Hodgson¹⁷ on September 1, 1859. This was followed by a severe magnetic storm. Further direct evidence substantiating the ultra-violet light theory seems to be lacking, although the sun has been observed for many years by numerous observers who could hardly fail to see such an outstanding change in the sun's brightness.

Another theory that has long been held as a possible cause of disturbed terrestrial phenomena assumes the disturbing emanation from

¹⁴ "Sun-spots and magnetic storms," *Monthly Notices of the Royal Astronomical Society*, **65**, 186-197; January, 1905.

¹⁵ H. B. Maris and E. O. Hulburt, "Ultra-violet light of the sun as origin of aurora and magnetic storms," *Nature*, **122**, 807-808; November 24, 1928.

H. B. Maris and E. O. Hulburt, "A theory of auroras and magnetic storms," *Phys. Rev.*, **S2**, **33**, 412-431; March, 1929.

H. B. Maris and E. O. Hulburt, *Proc. I.R.E.*, **17**, 494-500; March, 1929.

E. O. Hulburt, "On the ultra-violet light theory of aurorae and magnetic storms," *Phys. Rev.*, **34**, 344-351; July 15, 1929.

E. O. Hulburt, "The ultra-violet light theory of auroras and magnetic storms," *Phys. Rev.*, **35**, 1587; June 18, 1930.

¹⁶ "Description of a singular appearance seen in the sun on September 1, 1859," *Monthly Notices Royal Astronomical Society*, **20**, 13-15; September, 1859.

¹⁷ "On a curious appearance seen in the sun," *Monthly Notices Royal Astronomical Society*, **20**, 15-16; September, 1859.

the sun to be charged particles. This has been extensively developed for auroras by C. Stormer¹⁸ and for magnetic storms by Chapman.¹⁹ Observations made on solar prominences, principally by Pettit,²⁰ show that eruptive prominences are shot out from the sun with increasing velocity; and that velocities have been measured, before the prominence became too rare for observations, which would project the matter to the earth in approximately a day and a half. Pike²¹ has shown that these motions are the necessary result of selective radiation pressure.

It is fairly well established that a magnetic storm, beginning today, establishes a probability that another will occur approximately 27 days hence. The approximation to 27 days is close enough to indicate that the original source of disturbance rotates substantially with the sun, and moreover, that it must have the same approximate position relative to the earth for each magnetic storm in the series. In fact, there is now a considerable body of evidence that this position is apt to be near the center of the sun's disk.²² This strongly suggests that the radiation

¹⁸ "Cause of magnetic storms," *Comptes Rendus*, **147**, 733-735; October 26, 1908.

"Corpuscular theory of the aurora borealis," *Terr. Mag. and Atmos. Elec.*, **22**, 23-24; March, 1917; and **22**, 97-112; September, 1917.

"Passage of Alpha and Beta particles through the earth's atmosphere," *Comptes Rendus*, **170**, 742-744; March 22, 1920.

¹⁹ S. Chapman, "An outline of a theory of magnetic storms," *Proc. Roy. Soc. (London)*, **A95**, 61-83; October 7, 1918.

S. Chapman, "On the certain characteristics of world wide magnetic disturbances," *Proc. Roy. Soc. (London)*, **A115**, 242-267, 1927.

S. Chapman, "Solar streams of corpuscles," *Monthly Notices of the Royal Astronomical Society*, **89**, 456-470; March, 1929.

S. Chapman and V. C. A. Ferraro, "Electrical state of solar streams of corpuscles," *Monthly Notices of the Royal Astronomical Society*, **89**, 470-479; March, 1929.

S. Chapman, "A new theory of magnetic storms," *Nature*, **126**, 128-130; July 26, 1930.

Lindeman, "Note on the theory of magnetic storms," *Phil. Mag.*, **38**, 664-684, 1919.

²⁰ Since the writing of this paper, a paper by S. Chapman and V. C. A. Ferraro on, "A new theory of magnetic storms, Part I, the initial phase," has appeared in *Terr. Mag. and Atmos. Elec.*, **36**, 77-97; June, 1931. This contains an extensive bibliography on the theory of magnetic storms. E. Pettit, "The forms and motions of the solar prominences," *Pub. of the Yerkes Obs.*, **3**, pt. 4, pp. 205-239 + 37 plates.

²¹ S. R. Pike, "The motions of gases in the sun's atmosphere," *Monthly Notices of the Royal Astronomical Society*, **88**, 3-30; November, 1927.

²² E. W. Maunder, "Great magnetic storms 1875 to 1903," *Monthly Notices of the Royal Astronomical Society*, **64**, 205; January, 1904.

E. W. Maunder, "Magnetic disturbances 1882 to 1903 as recorded at the Royal Observatory, Greenwich, and their association with sun-spots," *Monthly Notices of the Royal Astronomical Society*, **65**, 2-34. Maunder states that the magnetic disturbances themselves supply absolutely conclusive evidence that they are due to action along definite restricted lines.

W. M. H. Greaves and H. W. Newton, "Large magnetic storms and large sun-spots," *Monthly Notices of the Royal Astronomical Society*, **88**, 556-567; May, 1928. Page 561—"The circumstances that 16 out of 17 very large magnetic storms occur within 4 days of the central meridian passage of a striking solar disturb-

is fairly directional within a certain restricted angle. The solar streams of Chapman's theory are assumed by him to be directional. Radiation pressure may be mentioned as a definite agency which will tend to bring this about. On the other hand, it seems more difficult to point to a mechanism which might produce an ultra-violet beam, sufficiently directional to explain this strong tendency to a 27-day period. It may also be mentioned that eruptions on the sun, in which matter is seen to be projected toward the earth, have been photographed preceding terrestrial magnetic storms,²³ while observations on the "hot spots" required by the ultra-violet light theory are almost entirely lacking.

FIELD STRENGTH OF "STATIC"

The atmospheric noise at New Southgate has been determined by the same method as that by which the signal field strength is measured. The measurements show that the "static" field strength has a diurnal variation in phase with the diurnal variation of the signal. In other words, the "static" is greater when the signal is received than it is when the signal is unheard. Fig. 18 shows graphically the variation of the field strength of static. The top curves show the variation of the field strength of static with frequency during the summer; curve 1 shows the average daily maximum and curve 2 shows the average daily minimum. Both the absolute magnitude and the diurnal variation of the static field strength are less for the higher frequencies. In fact for the highest frequencies, 18, 22, and 28 mc, there is no noticeable diurnal

ance, points to an individual connection between magnetic storms and spots. But the 17th case is a reminder that a large storm may originate from a solar disturbance which manifests itself as a small spot only, or possibly from something which does not manifest itself as a spot at all."

W. M. H. Greaves and H. W. Newton, "Magnetic storms and solar activity 1874 to 1927," *Monthly Notices of the Royal Astronomical Society*, 89, 84-92; November, 1928.

G. W. Pickard, "The correlation of radio reception with solar activity and terrestrial magnetism," *Proc. I.R.E.*, 15, 83-97; February, 1927. Page 96—"I find that, in general, reception is most affected when a spot or group of spots is near the center of solar disc, that is, when they most nearly face the earth, although there are exceptions."

G. W. Pickard, "The correlation of radio reception with solar activity and terrestrial magnetism. II." *Proc. I.R.E.*, 15, 740-877; September, 1927.

G. W. Pickard, "The relation of radio reception to sun spot position and area," *Proc. I.R.E.*, 15, 1004-1012; December, 1927.

²³ George Hale, "The spectroheliograph and its work," *Astrophysical Journal*, 70, 309 and references given here.

H. W. Newton, "An active region on August 12, 1930," *M.N.R.A.S.*, 90, 820-825. (See references given in this article.)

Royal Observatory, Greenwich, "A solar eruption on November 25, 1930," *M.N.R.A.S.*, 91, 239-241; December, 1930.

variation.²⁴ During the winter both the diurnal variation and the magnitude of the static are less than during the summer as shown by curves 3 and 4.

At the bottom of Fig. 18, the variation of the static field strength with time of year is plotted by frequencies. Here as before the upper curve is the maximum of the diurnal variation and the lower curve is the minimum of the diurnal variation.

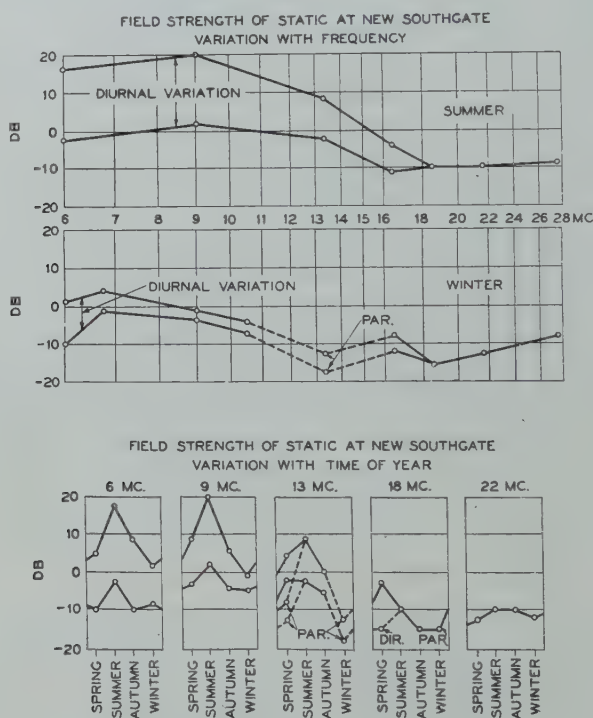


Fig. 18—Variation of the field strength of static.

Some of the measurements were made with directive receiving antennas. This is indicated on the sketch by "par" for a receiving antenna with a parabolic reflector and by "dir" for a directive array. While data taken with the directive antennas are for a different year than those on nondirective antennas, the data show that there is a definite decrease in the field strength of static due to the directivity of the receiving antenna.

²⁴ A small diurnal variation, if present, might not have been detected by these tests since at times the set noise precluded a measurement of the field strength of static.

CONCLUSIONS

"Normal" transmission conditions over the transatlantic path in summer are shown in Fig. 13. These indicate that frequencies near 18 mc are the best for daytime transmission and frequencies near 9 mc for nighttime. An intermediate frequency near 13 mc is required during the morning transition period. Fig. 14 shows the "normal" transmission conditions in winter. The skip valley is enlarged and the absorption valley reduced, as would be expected from decreased exposure of the path to the ionizing effect of the sun. There is also better transmission on the higher frequencies during the period of total daylight. This would be explained if it were found that the ionized layer were in a region of lower molecular density in winter than in summer. In winter the range of best day frequencies is larger, the field strengths being as great on 13 mc as on 18 mc. Other considerations may require 18 mc for daytime transmission. A frequency near 13 mc is necessary as a transition frequency. During the evening and early morning, frequencies near 9 mc are useful, while a frequency near 6 mc is required during the middle of the night.

Over North Atlantic paths a very careful choice of frequencies is necessary in order to obtain the best service possible. Experience has shown these paths to be more susceptible to disturbed solar conditions than those farther south. The five hours difference in time at the terminals and the irregular day-to-day variations contribute to the need for frequent changes in frequency.

The effect of solar disturbances on short wave transmission over this path is always to reduce the received signal. If the disturbance is not too severe, better transmission results on frequencies slightly lower than on those that would normally be employed.

The diurnal variation of the atmospheric noise at New Southgate, England, is in phase with that of the received signal. The field strength of the atmospheric noise is given in Fig. 18. In summer it is greater and also has a larger diurnal variation than in winter. On the higher frequencies it is smaller and has a smaller diurnal variation than on the lower frequencies.

The author is indebted to J. C. Schelleng whose consultation he has found extremely helpful. Acknowledgement is also due to A. G. Jensen who was in charge at New Southgate, and under whose supervision these data were obtained.

LONG-DISTANCE TRANSMISSION OF STATIC IMPULSES*

BY

S. W. DEAN

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DURING the operation of the long-wave transatlantic radio-telephone circuit, it has been noticed that strong crashes of static are often heard simultaneously at the two ends of the circuit. It is not unreasonable that this should be the case as there is considerable evidence in previous experience pointing to the propagation of static crashes over extremely long distances.¹

In order to obtain an oscillographic record of such occurrences, an effort was made on June 21, 1927, to transmit the static received at Houlton, Maine, to New Southgate near London, where it could be recorded on an oscillograph simultaneously with static transmitted to New Southgate from Cupar, Scotland. In order to transmit the Houlton static across the ocean with the minimum interference from local static on the English side of the ocean, the short-wave channel from Deal Beach, New Jersey, to New Southgate was chosen. The static from Houlton was transmitted to Deal Beach over a telephone circuit. The transmissions from Deal Beach were picked up directly at New Southgate on a short-wave receiving set. The static from Cupar was transmitted to New Southgate over a telephone line. As an additional precaution against the effect of local static on the short-wave receiver at New Southgate, an additional short-wave monitoring receiver was provided at that point whose output would indicate any local crashes strong enough to affect the receiver which was tuned to Deal Beach.

A reproduction of the oscillogram obtained is shown in Fig. 1. The upper record represents the static received at Houlton and transmitted across the ocean via the short-wave channel. The middle record shows the static received at Cupar. The lower record is that of the short-wave monitoring receiver. Timing marks are shown on the record by displacement of the short-wave spot at one-minute intervals. It should be noted that one of these timing marks occurred during a blank interval on the oscillogram and, therefore, is not shown. There were also

* Decimal classification: R113X114. Original manuscript received by the Institute, May 29, 1931.

¹ M. Bäumlér, "Simultaneous atmospheric disturbances in radio telegraphy," *Proc. I.R.E.*, **14**, 765; December, 1926.

The Range of Atmospherics—Report from the Committee on the Relation between Atmospherics and Weather, of the Royal Meteorological Society.

apparently no timing marks on the first portion of the oscillogram. The rate of film travel determined from these marks was approximately $11\frac{1}{2}$ inches per minute.

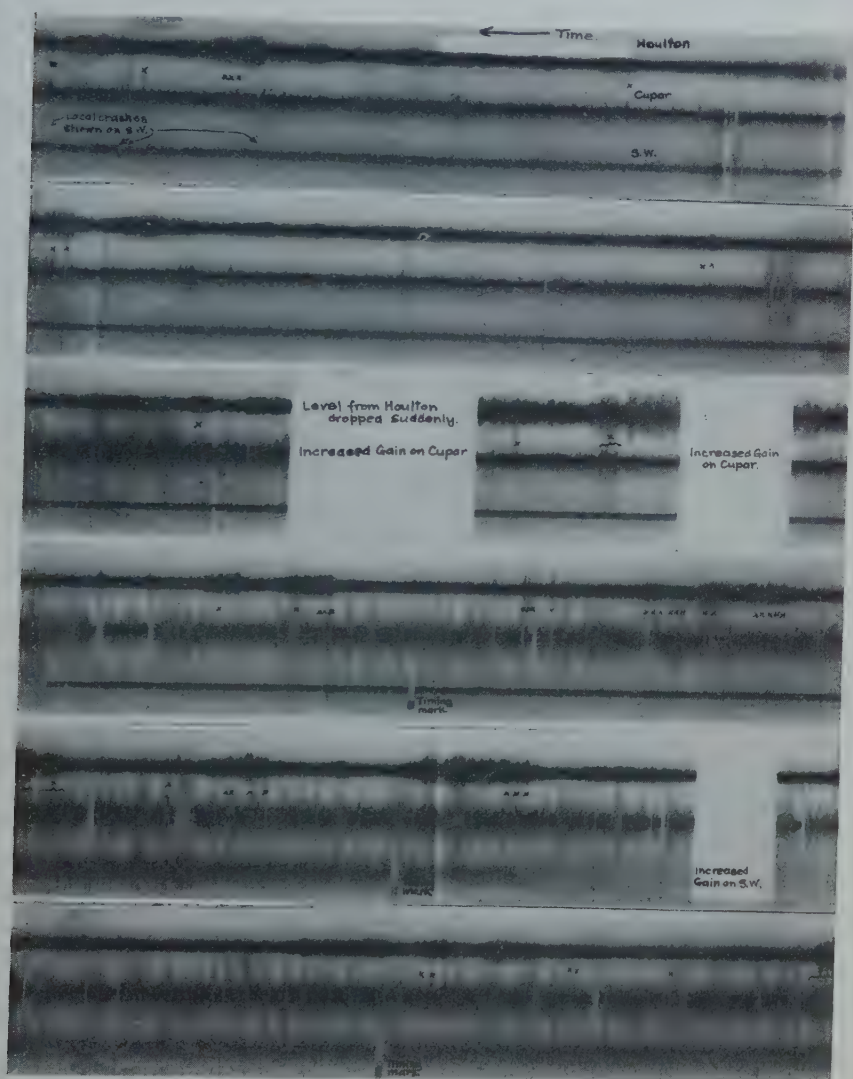


Fig. 1—Oscillogram showing atmospherics received simultaneously at Houlton, Maine, (long-wave); Cupar, Scotland, (long-wave); and New Southgate, England, (short-wave).

An examination of the oscillogram shows a large number of simultaneous crashes at Cupar and Houlton. Some of the most striking of

these are marked by small x's. The detail correspondence of some of these records is quite remarkable. Unfortunately, the relative amplitudes of the three records were not always the best, and due allowance for this must be made in interpreting the results. For instance, on the last part of the oscillogram the gain of the short-wave monitoring receiver was so great that the set noise produced deflections which overlapped the Cupar record the greater part of the time.

This oscillogram, together with previous evidence on the subject, leaves little doubt that strong atmospheric disturbances are often propagated 3000 miles or more

This experiment was made possible by the coöperation of the British General Post Office, R. A. Watson Watt of the British Radio Research Board, A. G. Jensen of the Bell Telephone Laboratories, and R. K. Potter of the American Telephone and Telegraph Company.



THE RELATION CONNECTING SKIP DISTANCE, WAVELENGTH, AND THE CONSTANTS OF THE IONIZED LAYERS*

By
N. H. EDES

(Captain, Royal Signals, Attached Royal Canadian Signals, Camp Borden, Ont., Canada)

Summary—Neglecting the short-range ground ray, it is assumed that short-wave propagation is due to single or multiple total reflection between the earth and one or more ionized layers in the atmosphere. For single reflection at a single layer an equation is developed giving the wavelength in terms of the skip distance, the height of the layer and the degree of ionization of the layer. The curve represented by this equation is discussed.

The equation, in conjunction with experimental data, shows the height of the layer which governs the skip distance in daylight to be about 230 km, and its ionization about 7.0×10^5 electrons per cu. cm. It is thought that, in daylight, higher layers of greater ionization do not exist. But there may be lower ones of lesser ionization.

The theory is then applied to the case of multiple reflection in daylight. The data lead to a value of 10.4 meters for the shortest useful wavelength for daylight work.

The case of two or more layers is next discussed, and experimental data for darkness are used, by means of the theory, to estimate the structure of the ionized regions at night. On winter nights there appear to be at least two layers, one at a height of about 520 km and with an ionization of about 2×10^5 electrons per cu. cm., the other at a height of the order of 40 km and with an ionization of the order of 3.5×10^4 electrons per cu. cm. On summer nights there is a layer at a height of about 230 km and with ionization of about 6.3×10^5 per cu. cm., and, in addition a low-lying layer of small ionization (10 km, and 6.7×10^3 electrons per cu. cm.).

DEFINITION OF SKIP DISTANCE

BY SKIP distance is meant the distance, measured along the earth's surface, from a station sending on a given wavelength, to the place where signals first become audible. (Signals due to the ground ray are neglected.)

THE PROBLEM UNDER DISCUSSION

The problem may be stated in either of two ways: (a) For known atmospheric conditions, what is the skip distance associated with any given wavelength? or (b) for the known conditions, what is the shortest wavelength that will give readable signals at any given distance?

Put in yet another way, the paper sets out to discuss the shape of the lower dotted curves in Fig. 7 of the author's previous paper.¹

* Decimal classification: R113. Original manuscript received by the Institute, April 13, 1931.

¹ N. H. Edes, "Some experiences with short-wave wireless telegraphy," *Proc. I.R.E.*, 18, 2030; December, 1930.

SYMBOLS USED

- h The height in km of an ionized layer above the surface of the earth.
- $R = 6371$ The radius of the earth in km.
- N The ionization of the layer, i.e., the number of electrons per cu. cm.
- μ The refractive index of the layer as compared with that of air.
- $e = 1.59 \times 10^{-20}$ The charge on an electron, in electromagnetic units.
- $m = 8.97 \times 10^{-28}$ The mass of an electron in grams.
- $A = 1.115 \times 10^9$ The constant $\pi m / 10^4 \cdot e^2$
- λ A given wavelength, measured in meters.
- x The skip distance, in km, associated with the wavelength λ .†
- λ_0 The wavelength in meters for which the refractive index of a given ionized layer is zero, i.e., the shortest wavelength for which all rays are totally reflected by the layer—even those rays which meet the layer perpendicularly.
- θ Half the angle, in radians, subtended by x at the center of the earth.
- ϕ The angle of incidence of a ray meeting the layer.

NOTE: The equations in this paper need no modification if h , R , and x are all expressed in miles, or any other unit of length, instead of in km.

ASSUMPTIONS MADE AND RELATIONS RESULTING FROM THEM

A ray traveling between the earth and an ionized layer is assumed to follow an approximately straight line. On meeting the layer it is either transmitted, or totally reflected in accordance with the laws of light. If totally reflected, its distance of penetration into the layer is taken to be negligible.

The conductivity of the layer is supposed to be entirely due to the presence of free electrons. This supposition gives:

$$\mu = \sqrt{\left\{1 - \frac{10^4 e^2}{\pi m} N \lambda^2\right\}} = \sqrt{\left\{1 - \frac{N}{A} \lambda^2\right\}} = \sqrt{\left\{1 - \frac{\lambda^2}{\lambda_0^2}\right\}} \quad (1)$$

And,

$$\lambda_0 = \sqrt{\frac{A}{N}} \quad (2)$$

† Alternatively, x may be regarded as a given range and λ as the shortest wavelength necessary in order to get communication over that range.

At the critical angle,

$$\begin{aligned}\sin \phi &= \mu \\ \therefore \cos \phi &= \sqrt{1 - \mu^2} = \frac{\lambda}{\lambda_0}\end{aligned}\quad (3)$$

EQUATION FOR SINGLE REFLECTION AT A SINGLE LAYER

In Fig. 1 let A and B be sending and receiving stations, O the center

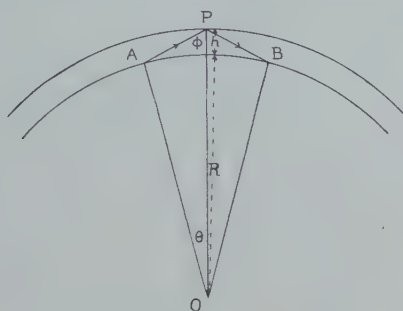


Fig. 1—Single reflection at a single layer.

of the earth, and P the point where the ray causing communication is reflected by the layer.

From the triangle OAP :

$$\frac{\sin \phi}{R} = \frac{\sin (\theta + \phi)}{R + h}$$

$$\therefore (R + h) \sin \phi = R(\sin \theta \cos \phi + \cos \theta \sin \phi)$$

$$\therefore \tan \phi = \frac{R \sin \theta}{R + h - R \cos \theta} \quad (4)$$

$$\therefore \sec^2 \phi = 1 + \tan^2 \phi = \frac{2R^2 - 2R(R + h) \cos \theta + 2Rh + h^2}{(R + h - R \cos \theta)^2}$$

$$\therefore \frac{\lambda}{\lambda_0} = \cos \phi = \frac{R + h - R \cos \theta}{\sqrt{2R^2 - 2R(R + h) \cos \theta + 2Rh + h^2}}$$

Now h is, in general, small compared with R , and for a single reflection θ is in general a small angle. Therefore, substituting $\cos \theta = 1 - \theta^2/2! + \theta^4/4! - \dots$ etc., we get, to the second order of small quantities:

$$\frac{\lambda}{\lambda_0} = \frac{h + \frac{R\theta^2}{2}}{\sqrt{R^2\theta^2 + h^2 + Rh\theta^2}}$$

But,

$$\theta = \frac{x}{2R}$$

$$\therefore \frac{\lambda}{\lambda_0} = \frac{x^2 + 8Rh}{4R \sqrt{\left\{ x^2 \left(1 + \frac{h}{R} \right) + 4h^2 \right\}}} \quad (5)$$

Remembering that from (2) $\lambda_0 = \sqrt{A/N}$, we see that (5) is the required relation connecting x , λ , h , and N .

DISCUSSION OF THE EQUATION

The general form of the curve represented by (5) is shown in Fig. 2.

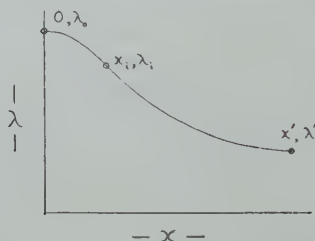


Fig. 2— λ_0 —Maximum value of λ . It occurs when $x=0$.
 λ' —Minimum value of λ .
 x' —Value of x corresponding to $\lambda=\lambda'$.
 (x_i, λ_i) —Point of inflection.

Consideration of the equation leads to the following table, which will be found useful for comparing experimental results with the theory here developed. Column I shows some of the cardinal features of the curve; Column II shows their value as derived from (5); Column III shows approximations for these values; and Column IV shows grosser approximations which are often useful. p has been written for the (usually) small ratio h/R .

Columns III and IV may be used in conjunction for comparatively accurate calculation of the quantities concerned, by the method of successive approximations.

It may be noted from (5) that, if we write X for x^2 and Λ for λ^2 , the curve connecting X and Λ is part of a hyperbola.

AN ACCURATE TRIGONOMETRICAL METHOD

Equation (4) may be written:

$$\cot \phi = \frac{R + h}{R} \operatorname{cosec} \theta - \cot \theta, \quad (15)$$

TABLE I

I	II	III	IV	
λ_0	$\sqrt{\frac{A}{N}}$			See (2)
$\frac{d\lambda}{dx}$	$-\frac{\lambda_0}{4R} \cdot x \cdot \frac{8Rh - x^2(1+p)}{\{x^2(1+p) + 4h^2\}^{3/2}}$			(6)
$\frac{\lambda'}{\lambda_0}$	$\sqrt{\frac{2h}{R}} \cdot \frac{\sqrt{\left(1 + \frac{p}{2}\right)}}{1+p}$	$\sqrt{\frac{2h}{R}} \cdot \left(1 - \frac{3p}{4}\right)$	$\sqrt{\frac{2h}{R}}$	(7)
x'	$2\sqrt{\left(\frac{2Rh}{1+p}\right)}$	$2\sqrt{(2Rh)} \cdot \left(1 - \frac{p}{2}\right)$	$2\sqrt{(2Rh)}$	(8)
$\frac{x'\lambda'}{\lambda_0}$	$\frac{\sqrt{\left(1 + \frac{p}{2}\right)}}{4h} \cdot \frac{4h}{(1+p)^{3/2}}$	$4h \left(1 - \frac{5p}{4}\right)$	$4h$	(9)
λ_0	$2R \cdot \frac{\lambda'}{x'} \cdot \sqrt{\left(\frac{1+p}{1+\frac{p}{2}}\right)}$	$2R \cdot \frac{\lambda'}{x'} \cdot \left(1 + \frac{p}{4}\right)$	$2R \cdot \frac{\lambda'}{x'}$	(10)
$\frac{\lambda_i}{\lambda_0}$	$\sqrt{\frac{2}{3}} \cdot \left(\frac{1+2p}{1+\frac{7p}{4}}\right) \sqrt{\left(\frac{1+\frac{3p}{4}}{1+\frac{p}{2}}\right)}$	$\sqrt{\frac{2}{3}} \cdot \left(1 + \frac{3p}{8}\right)$	$\sqrt{\frac{2}{3}}$	(11)
x_i	$\frac{\sqrt{2 \cdot h}}{\sqrt{\left\{(1+p)\left(1 + \frac{3p}{4}\right)\right\}}}$	$\sqrt{2 \cdot h} \left(1 - \frac{7p}{8}\right)$	$\sqrt{2 \cdot h}$	(12)
Slope at inflection	$\frac{\lambda_0}{3\sqrt{3 \cdot h} \sqrt{\left\{(1+p)\left(1 + \frac{p}{2}\right)\right\}}}$	$-\frac{\sqrt{3}}{9} \cdot \frac{\lambda_0}{h} \left(1 - \frac{3p}{4}\right)$	$-\frac{\sqrt{3}}{9} \cdot \frac{\lambda_0}{h}$	(13)
$\frac{x_i^2}{x_i}$	$4\sqrt{2 \cdot R} \cdot \sqrt{\left(\frac{1+\frac{3p}{2}}{1+p}\right)}$	$4\sqrt{2 \cdot R} \left(1 - \frac{p}{8}\right)$	$4\sqrt{2 \cdot R}$	(14)

Suppose h and N (or λ_0) are known. For any value of x , $\theta = x/2R$, and $\operatorname{cosec} \theta$ and $\cot \theta$ can then be found from trigonometrical tables. Substituting these values in (15) we can find $\cot \phi$, and therefore ϕ . Then λ can be found, since from (3) $\lambda = \lambda_0 \cos \phi$.

This method involves no approximations other than those in the trigonometrical tables.

DISCONTINUITY ON PROCEEDING TO HIGHER ORDER OF REFLECTION

It is evident from Fig. 1 that θ has its greatest possible value when the ray leaves the sending station tangentially to the earth. From (4)

we see that ϕ increases with increase of θ . Therefore, when the ray is tangential, $\cos \phi$ has its least possible value; also $\theta + \phi = \pi/2$.

But from (3), $\lambda/\lambda_0 = \cos \phi$. Therefore, λ has its least possible value when the ray is tangential. This has been pointed out by Eckersley.²

Now when the ray is tangential, $\cos \theta = R/(R+h) = (1+p)^{-1}$

$$\begin{aligned}\therefore 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} - \dots &= 1 - p + p^2 - \dots \\ \therefore \frac{x^2}{4R^2} &= \theta^2 \div 2p(1-p) \\ \therefore x &\div 2\sqrt{2Rh} \cdot \left(1 - \frac{p}{2}\right)\end{aligned}$$

And,

$$\begin{aligned}\lambda &= \lambda_0 \cos \phi = \lambda_0 \sin \theta = \lambda_0 \sqrt{\left\{1 - \left(\frac{R}{R+h}\right)^2\right\}} \\ &= \lambda_0 \sqrt{\frac{2h}{R} \cdot \frac{\sqrt{1 + \frac{p}{2}}}{1 + p}}\end{aligned}$$

But these are the values of x and λ (derived from (5)) for which λ is a mathematical minimum (see the Table). The mathematical minimum shown in Fig. 2 therefore occurs at the range which is, physically, the greatest that can be obtained with a single reflection. Physical reasons therefore preclude our continuing the curve of Fig. 2 beyond the point at which λ is a minimum, namely the point representing tangency between the ray and earth.*

Still considering the grazing ray, let us increase the wavelength. The ray will be reflected, and will touch the earth at the same point as before. Therefore for a single reflection the value of the greatest range obtainable is independent of the wavelength. To get a greater range we need at least two reflections. It follows that in order to extend the curve to portray the greater ranges we must proceed in the way described by the author when discussing the question of "best wavelength."³ The curve will then be as shown in Fig. 3.

² T. L. Eckersley, "Multiple signals in short-wave transmission," *Proc. I.R.E.*, 18, 115; January, 1930.

* The same result may be obtained by differentiating the equation from which we obtained (4), viz.:

$$\frac{\sin \phi}{R} = \sin \frac{(\theta + \phi)}{R + h}$$

$d\phi/d\theta$ will be found to be positive until $\theta + \phi = \pi/2$, when it becomes zero. This shows that ϕ is a maximum and λ a minimum when the ray is tangential.

³ Edes, "The multiple refraction and reflection of short waves," *Proc. I.R.E.*, 19, 1024-1033; June, 1931.

The curve for ranges needing n reflections will be the last n -th portion of the curve for single reflection with its scale along the x -axis increased n -fold. From both mathematical and physical considerations it is easy to show that there is the same minimum value of λ (namely λ') at the end of every stage of the characteristic.

By this method and (5) or (15) we can, if we know h and N , construct the skip distance or lower wavelength characteristic for all ranges.

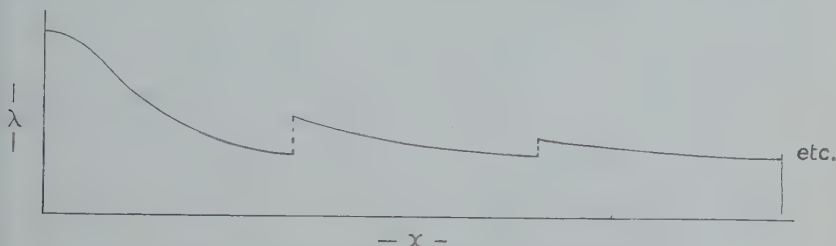


Fig. 3—Multiple reflection at a single layer.

THE THEORY APPLIED TO RESULTS OBTAINED IN PRACTICE

In Fig. 4 are reproduced experimental curves marked (a) and (b) obtained by the author for summer daylight and winter daylight.¹ They suggest a value of about 40 for λ_0 .

On the same scale are plotted the curves marked (c) and (d) given by (5) for the values (c) $\lambda_0 = 40$, $h = 220$, and (d) $\lambda_0 = 40$, $h = 240$. If 40 is not quite the right value for λ_0 we ought to increase or decrease all the ordinates of curves (c) and (d) in the same ratio.

The figure shows that in daylight the height of the reflecting layer lies between about 220 and 240 km. We can get the ionization of the layer by substituting $\lambda_0 = 40$ in (2). This gives a value of 7.0×10^5 electrons per cu. cm. We can calculate λ' and x' from (7) and (8); taking λ_0 as 40 and h as 230 they come to about 10.4 meters and 2100 miles. Or we can find them from the fact that for the tangential ray $\cos \theta = R/(R+h)$. In the present case this gives $\theta = 15^\circ 9'$. Hence $x' = 2R\theta$ can be found. And since at tangency $\lambda/\lambda_0 = \sin \theta$, we get $\lambda' = 40 \sin 15^\circ 9'$. This method gives the same figures as those from (7) and (8).

These values are in remarkably close agreement with those given by Appleton,⁴ Breit, Tuve, and Dahl,⁵ and Eckersley.² It is to be noted, however, that Breit, Tuve, and Dahl, and Eckersley find a daytime

¹ *Loc. cit.*

⁴ E. V. Appleton, Letter in *Nature*, **123**, 445; March, 1929.

⁵ Breit, Tuve, and Dahl, *Proc. I.R.E.*, **16**, 1236; September, 1928.

² Eckersley, *loc. cit.*

layer of high ionization at a height of 340 km. The present results are not in agreement with this. This question will be referred to later on. The value now found for the ionization of the 230-km layer agrees well with that in Eckersley's table, but apparently disagrees with that in his diagram.⁶

MORE THAN ONE LAYER

We must now consider what happens if there are two or more layers at different heights and with different degrees of ionization.

For simplicity we will only deal with the case of two layers, the higher one having a much greater ionization than the lower one.

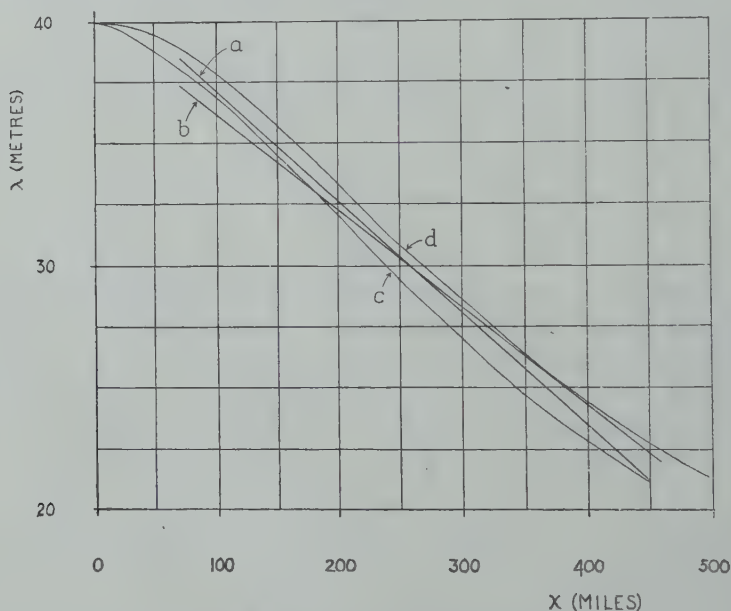


Fig. 4—(a)—Experimental curve for summer daylight.
 (b)—Experimental curve for winter daylight.
 (c)—Theoretical curve for $\lambda_0 = 40$ $h = 220$.
 (d)—Theoretical curve for $\lambda_0 = 40$ $h = 240$.

Knowing h and N for each layer we can plot the two characteristics P_1Q_1 etc., and $p_1q_1p_2q_2$ etc., as in Fig. 5.

Let P_1Q_1 and p_1q_1 cut at S . Now, except for wavelengths shorter than that given by the ordinate of q_1 , the abscissa of S gives the greatest range attainable by rays singly reflected by the higher layer—since rays emitted at flatter angles than that corresponding to S are reflected by the lower layer and never reach the higher one. This is represented

⁶ Eckersley, *loc. cit.*, p. 112 and Fig. 3 respectively.

by the branch Sq_1 . For double reflection at the higher layer we must carry out the construction already described, starting from S . This gives us TU , which is the second half (horizontally reckoned) of P_1S with its horizontal scale doubled.

Similarly p_2q_2 is the characteristic for double reflection at the lower layer.

Now it will be seen that the portion TW for the higher layer is masked by the portion Sq_1 for the lower layer; while the portion p_2U

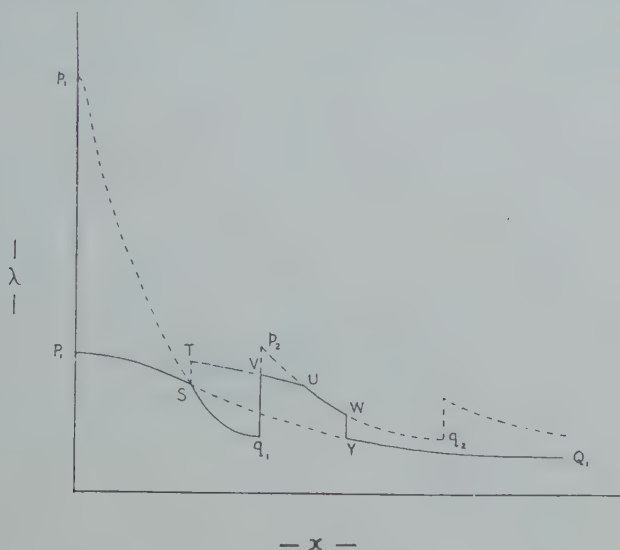


Fig. 5—Two layers.

for the lower layer is masked by the portion VU for the higher layer. The skip distance curve that would be found by experiment is therefore as shown by the full line in Fig. 5. Proceeding beyond U we get the portion UW representing double reflection at the lower layer, and we then come to YQ_1 representing single reflection at the higher layer of the waves so short that they always penetrate the lower layer.

And so the characteristic can be extended. The above is merely given as an example. The actual form of the characteristic depends on the relative values of the constants of the layers.

If, as is possible, the characteristics do not cross, considerations of skip distance (to which this paper is confined) will lead to the identification of one layer only, namely the one with the smaller value of λ_0 , i.e., with the larger value of N . This will probably be the higher layer of the two. The results for daylight therefore seem to conflict with

those of Breit, Tuve, and Dahl, and of Eckersley, but not with those of Appleton. That is, the results seem to belie the existence of a layer at 340 km, but to allow of (yet not to reveal) a layer at 100 km.

We have tacitly assumed that a ray passing through a layer is undeviated in its course to the next layer or to the earth as the case may be. This is approximately true only if the space between the layers is un-ionized and the layer penetrated is thin.

It should be noted that multiple reflection between two layers cannot take place if each layer is uniform. For if a ray has penetrated the lower layer it will, after reflection at the higher layer, penetrate the lower layer again.

EXPERIMENTAL EVIDENCE OF MORE THAN ONE LAYER

From the foregoing it is clear that the existence of a multiplicity of layers will greatly complicate the interpretation of experimental results.

Our investigation of the results for full daylight conditions seems to indicate that skip distance in daytime is determined by one layer only. When, however, we examine the curves for darkness we find that the hypothesis of a single governing layer will not fit the facts. For instance the curve given by the author for winter darkness in China¹ cannot be made to obey (5), no matter what values are chosen for h and N . It is thought that the curve can be divided into two different portions representing single reflection from two separate layers; the portions suggested are those denoting ranges from about (a) 0 to 650 miles and (b) 650 to 900 miles. Experience in China suggests a value of about 75 meters for λ_0 for the higher layer (a). This, in conjunction with the curve, suggests very roughly a value of 520 km for h . Also $\lambda_0 = 75$ meters gives $N \div 2 \times 10^5$ electrons per cu. cm. For the lower layer, the portion (b) seems to have values for x' and λ' of approximately 900 miles and 20 meters. These lead to $h \div 40$ km, $\lambda_0 \div 180$ meters and $N \div 3.5 \times 10^4$ electrons per cu. cm.

Thus, for winter darkness in the zone of latitude 30 to 40 degrees North, there is some evidence for the existence of two layers, rough estimates of the heights and ionizations being:

	1st. Layer	2nd. Layer
Height (km)	520	40
No. of electrons per cu. cm.	2×10^5	3.5×10^4

¹ *Loc. cit.*

The corresponding curve for summer darkness¹ is interesting. From the theory in the present paper it appears that $d\lambda/dx$ is always negative. The right-hand portion of the curve is therefore open to suspicion. When the curve was originally plotted, fairly reliable points had been obtained for the left-hand portion, and for the range 620 miles. For 450 miles there was evidence that λ had on occasions a value of about 33 meters. As this point lay off the smooth curve through the others, it was considered unreliable and discarded; and the curve was drawn as in the previous paper here quoted. With the fuller knowledge now acquired through investigation of the theory we see that the discarded point is likely to have been approximately correct. There would

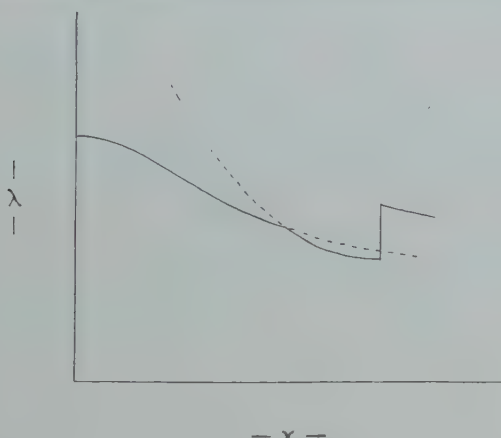


Fig. 6.

then be a discontinuity at a range of about 450 miles.† The right-hand portion of the curve would have a negative slope as required by the theory, and it would represent double reflection. But, even when thus modified, the curve cannot be made to fit (5) for a single layer. It can, however, be explained on the hypothesis of two layers possessing characteristics somewhat as sketched in Fig. 6.

The minimum at about 450 miles is considered to be due to the lower layer. The constants of the higher layer are not very different from those found for the daylight layer. Values of $h=230$, $\lambda_0=42$, $N=6.3 \times 10^5$ will be found to fit the curve tolerably well. For the lower layer we have $x' \doteq 450$ miles, $\lambda' \doteq 23$ meters. These give values of about 10 km for h , 410 meters for λ_0 and 6.7×10^3 for N .

¹ *Loc. cit.*

† It appears that, for these conditions, 450 miles is one of the "unfortunate" ranges alluded to in the author's paper on multiple reflection. See footnote 3.

The evidence is somewhat slender, but there is at least the suggestion that in summer darkness in latitudes of 30 to 40 degrees North two layers are operative, one of them being of low ionization and only a few miles above the surface of the earth. The constants very tentatively estimated for these layers are:

	1st. Layer	2nd. Layer
Height (km)	230	10
No. of electrons per cu. cm.	6.3×10^5	6.7×10^3

CONCLUSION

The theory propounded in the paper is in good agreement with the experimental data available for daylight.

In darkness, skip distance seems to be governed by more than one layer, and the data as yet available are insufficient to afford precise computation of the constants of those layers, or a complete test of the theory.

The acquirement of further data, especially for propagation in the hours of darkness, may lead to considerable progress not only in the art of radio communication but also in the science of geophysics.

Correction in previous paper, "The multiple refraction and reflection of short waves," *Proc. I.R.E.*, **19**, 1024-1033; June, 1931.

Page 1026 { line 2, for $1/2x$ read $x/2$
 line 5, for $2x/3$ read $x/3$
 line 6, for $(n-1/n) \cdot d$ read x/n



A CORRELATION OF LONG-WAVE RADIO FIELD INTENSITY WITH THE PASSAGE OF STORMS*

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Summary—*Variation in received field intensity of long radio waves is compared with variation of temperature, pressure, and rainfall during the passing of general storms at Washington. The results show that in general there is a definite falling off in signal intensity in front of the advancing low. This is followed by an increased intensity which persists from one to two days after the storm center passes. This indicates some real relationship between received signal strength of long waves and weather over that part of the path of the wave over which it passes shortly before reaching the receiving station.*

I. INTRODUCTION

DURING some cold periods of January, 1924, a marked increase in the received signal intensity of the Radio Corporation stations at Tuckerton and New Brunswick, N. J., was observed at Washington.¹ A later comparison, covering 1924 and 1925, between temperature and the daily signal observations of these stations indicated, in general, an inverse relationship between the two which was especially marked in winter.²

It had also been noted on many occasions that increased intensity of European long-wave stations often accompanied or followed the fall in temperature associated with the passage of low-pressure areas. (Fig. 1). This suggested a possible relationship between the propagation of long radio waves and surface meteorological conditions. In order to determine the probability of this relationship, a statistical study was made of the daily signal intensities of some of the long-wave European radio stations which have been measured at the Bureau of Standards for a number of years. A priori, any such correlation seemed very improbable, as a degree of ionization in the atmosphere sufficient to affect either reflection, refraction, or absorption of radio waves is believed to exist only at heights far above the regions to which the surface storms are confined.

II. METHOD OF USING THE OBSERVATIONAL MATERIAL

In this study the changes in received field intensity of certain long-wave European stations are examined in connection with the passing

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¹ L. W. Austin, Proc. I.R.E., 12, 681, 1924.

² L. W. Austin and I. J. Wymore, Proc. I.R.E., 14, 781, 1926.

of atmospheric lows, as evidenced by changes in temperature and barometer and by rainfall at Washington, and by temperature variations at Eastport, Maine. The study includes observations covering a six-year period from 1924 to 1929, inclusive. Since observations on the Radio Corporation stations had already given evidence of a relationship between received field intensity and temperature variations, after some consideration temperature drop was chosen as the primary indication of passage of the storms. In the winter, spring, and autumn months to which this analysis is confined, low-pressure areas are in general preceded by rising temperature, falling pressure, and rainfall.

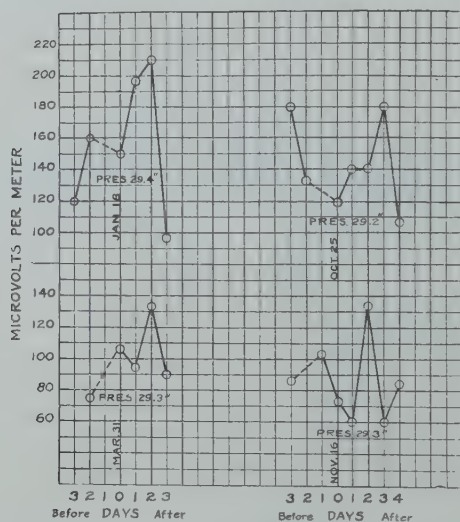


Fig. 1—Signals from Bordeaux (FYL) received at Washington during the passage of four typical storms in 1926.

In the rear of the moving storm, clear weather and lower temperatures obtain. The greatest fall in temperature from the day before generally indicates that the low is just passing and that higher pressures are becoming effective. This day of greatest temperature drop was used, therefore, as the center or zero day in the figures. Fig. 2 illustrates the method of selecting the center days; the arrows indicate the days chosen.

In this investigation, only those storms were considered during whose passage subnormal temperatures were registered at Washington. These included the majority of storms with which a drop of over 10 degrees F. was associated. For the six years under examination the average duration of continuous subnormal temperatures was 3.4 days. A five-day period centering on the day of the greatest temperature drop

is assumed to cover the time of signal variations due to the passage of the storm. To show this relationship, temperature, and signal gradient curves for this five-day period were drawn, and as further evidence of the progress of the storm, a rainfall and a pressure curve for Washington were added.

Because temperature drops in summer are more likely to be due to local causes, such as thunderstorms, the period from May 15 to September 15 was not included. It has been demonstrated that at times of severe magnetic storms (No. 2 days)³ the field strengths of long as well as short waves are often disturbed for several days before and after the storm. Therefore, all days falling on the day of any severe magnetic disturbance, or within four days before or after, were also excluded.⁴

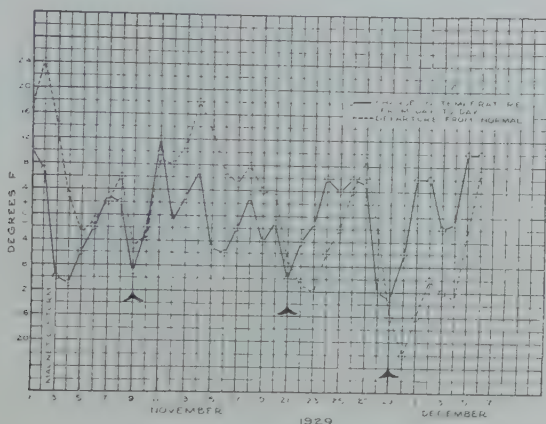


Fig. 2—Illustrations of method of obtaining zero days.
(Arrows indicate day chosen.)

The radio stations in Europe selected for this work were those lying in latitude 45–55 degrees N and within the frequency limits of 15 and 20 kc; Lafayette (FYL) near Bordeaux, Nauen (AGW) near Berlin, Ste. Assise (FU) near Paris, Rugby (GBR) in England, and Kootwijk (PCG) in Holland. The changes in field intensity of long-wave stations, while irregular, are generally much slower than those of shorter wavelengths, and their periods of strong or weak signals may last for a few hours or often for several days. Although it might be expected that the morning signals with all daylight paths would behave differently from

³ The Cheltenham Magnetic Observatory reports magnetic conditions as follows: 0—magnetically quiet days; 1—moderately disturbed days; 2—severely disturbed days.

⁴ Espenschied, Anderson, and Bailey, *Bell. Sys. Tech. Jour.* **13**, 459, 1925; I. J. Wymore, *Proc. I.R.E.*, **17**, 1206; July, 1929; C. N. Anderson, *Proc. I.R.E.*, **17**, 1528; September, 1929.

those of the afternoon which come from darkness into daylight, it is found that, in general, they rise or fall together, and, therefore, both were used in making up the averages. Table I shows a typical month of signal data giving the percentage deviation of the daily observations from the monthly averages of the stations. The final average used in the computations is an algebraic average of the deviations of the several

TABLE I
MARCH, 1925
DEVIATION FROM MONTHLY AVERAGE IN PER CENT

Day	10 A.M.			3 P.M.			Av.	Change
	LY	FU	AGW	LY	FU	AGW		
1	*	*	*	*	*	*	*	*
2	+27.1	+41.2	+15.4	*	*	*	+27.9	+3.8
3	+44.1	+29.4	+84.6	+37.6	+26.3	+84.6	+51.1	+23.2
4	*	*	*	*	*	*	*	*
5	-13.5	+17.6	+50.0	+56.0	-5.2	+7.7	+16.2	-34.9
6	+5.9	+29.4	+26.9	*	*	*	+20.7	+4.5
7	-18.6	-17.6	-7.7	-11.9	+42.1	+38.5	+4.1	-16.6
8	*	*	*	*	*	*	*	*
9	-18.6	-17.6	-7.7	-11.9	+10.5	+26.9	+3.0	-7.1
10	-8.5	*	-19.2	-11.9	-5.2	-42.3	-17.4	-14.4
11	+18.6	*	-17.3	+10.1	+42.1	+26.9	+16.0	+33.4
12	+27.1	-5.9	-30.8	-17.4	-21.1	+26.9	-3.5	-19.5
13	-39.0	-17.6	-30.8	+37.6	-5.2	*	-11.0	-7.5
14	-13.5	+29.4	-7.7	-11.9	+10.5	+15.4	+3.7	+14.7
15	*	*	*	*	*	*	*	*
16	+1.7	*	-19.2	-0.9	*	-19.2	-9.4	-13.1
17	-8.5	-5.9	-30.8	-11.9	-5.2	+50.0	-2.0	+7.4
18	-3.3	-5.9	-7.7	-56.0	-36.8	-42.3	-35.3	-33.3
19	-23.7	-29.4	-7.7	-17.4	-21.1	+38.5	-10.1	+25.2
20	+5.9	-29.4	+38.5	+21.1	*	*	+9.0	+19.1
21	+52.5	*	+15.4	+64.2	*	+26.9	+39.7	+30.7
22	*	*	*	*	*	*	*	*
23	+39.8	+29.4	+15.4	+46.8	+42.1	+3.8	+29.5	-10.2
24	+1.7	+29.4	+15.4	-17.4	-36.8	-42.3	-8.3	-37.8
25	+9.6	*	+3.8	-39.5	*	-30.8	-14.2	-5.9
26	-13.5	*	+15.4	+14.7	+26.3	+38.5	+16.2	+30.4
27	-8.5	+17.6	-19.2	-44.9	-21.1	-42.3	-19.7	-35.9
28	-49.1	-29.4	-61.5	-11.9	+10.5	-42.3	-30.6	-10.9
29	*	*	*	*	*	*	*	*
30	-23.7	-53.0	-30.8	-28.4	-36.8	-42.3	-35.8	-5.2
31	+5.9	*	-7.7	-0.9	-5.2	-30.8	-7.7	+28.1

* No observations.

stations for the day. The average signal change from day to day, that is, the difference in field intensity from one day to the next, was computed from this daily average percentage deviation. (See last column, Table I). These values were used in making up the curves for comparison with pressure, temperature, and rainfall. If one day's signal observations were missing, it was assumed that the change recorded on the following day took place uniformly over the two-day period.

The day-to-day pressure changes were computed from the 8 A.M. (75th Meridian time) barometric readings at Washington; the temperature changes from the daily temperatures measured at Washington and Eastport, Maine.

It was difficult in cases where the storms were separated by less than five days to determine whether the storm preceding or the one

following had the greater influence on the intervening observations. It was assumed that the weather conditions nearest the day in question would have the greater effect. If an observation occurred both on the first day after one zero day and two days before another it was aver-

TABLE II

Average length of subnormal temperature periods at Washington		No. of storms	No. of overlapping observations				
			Days before		Center	Days after	
			2	1		1	2
1924	3.4	31	3	2	0	2	3
1925	3.2	26	2	3	0	3	2
1926	3.5	24	3	1	0	1	3
1927	3.9	22	0	1	0	1	0
1928	3.8	25	2	1	0	1	2
1929	2.9	31	4	2	0	2	4

aged in the first group and not in the second. If the observations occurred on days which were removed from two center days by the same number of days, they were used in connection with both storms. The

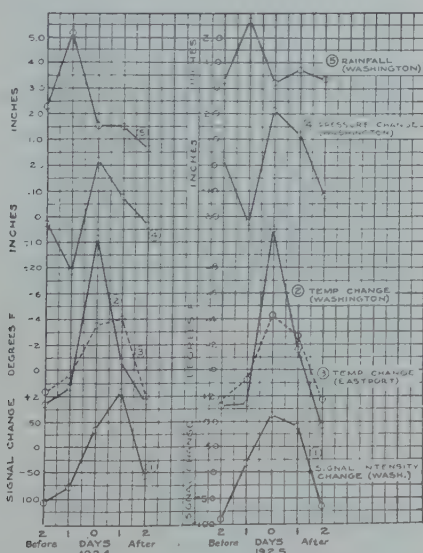


Fig. 3—Average daily percentage change of signal during the passage of storms over Washington, with accompanying changes in pressure, temperature, and rainfall for the years 1924 and 1925.

number of such overlapping observations and the days on which they occurred, as well as the number of storms considered, are given in Table II. This table shows that these overlapping observations are too few in number to have any marked influence on the averages.

The temperature and pressure curves (2, 3, and 4 in Figs. 3, 4, and 5) are made up of the average daily changes occurring at the times of the passing of the various storms for each year. The rainfall values (curve 5) were weighted by multiplying by the number of days on which rain fell. By this means emphasis was placed on general conditions of storminess rather than on the total rainfall. In computing these averages the minimum measurement (0.01 inch) was used where a trace, an amount too small to measure, was reported in the precipitation tables.

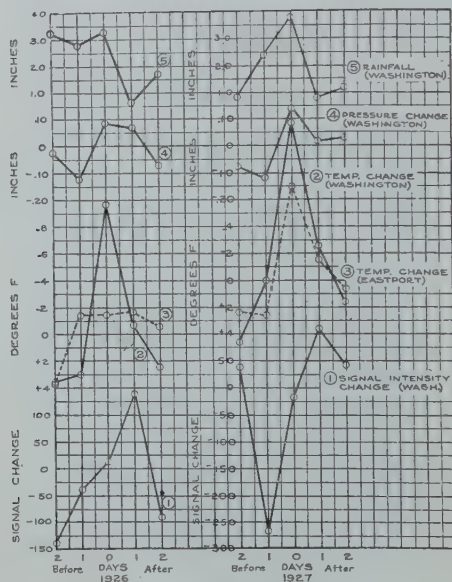


Fig. 4—Average daily percentage change of signal during the passage of storms over Washington, with accompanying changes in pressure, temperature, and rainfall for the years 1926 and 1927.

There were missing signal intensity values due to the absence of Sunday measurements and of observations on a few other days. The daily records are complete for pressure, temperature, and rainfall. Since averages containing the greater number of measurements are assumed to give the truer mean, the signal values were weighted by multiplying by the number of observations available in making up each average.

III. DISCUSSION OF RESULTING CURVES

In Figs. 3, 4, and 5 are shown curves of the average daily change, increasing or decreasing, in pressure, temperature, and signal intensity, and the average rainfall that occurred in the five-day periods centering

on the day of the greatest temperature drop during the storms of the years 1924, 1925, 1926, 1927, 1928, and 1929. While they include the majority of severe storms, these do not include all that passed Washington during these years because of the elimination of periods marked by severe magnetic disturbance and the exclusion of those storms in which the temperature did not fall below normal.

Curves 1, 2, 3, and 4 in Figs. 3 to 5 represent not only the relative magnitude of change from day to day, but also the duration of this change within the 5-day period. All values above the zero line show

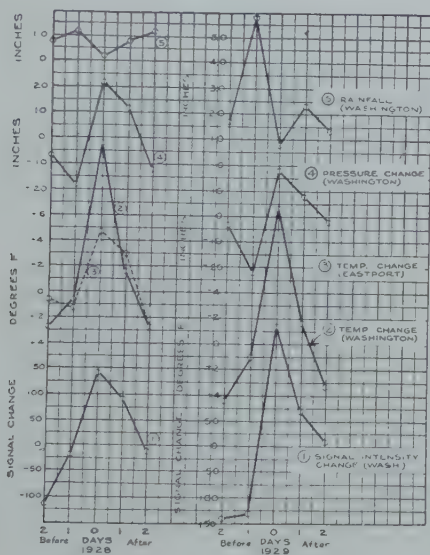


Fig. 5—Average daily percentage change of signal during the passage of storms over Washington, with accompanying changes in pressure, temperature, and rainfall for the years 1928 and 1929.

that, on the average, the change is upward; those below, downward. The temperature curve is inverted to facilitate comparison. Curve 5 is composed of the relative rainfall values (midnight to midnight).

The center day, and, in most cases, the few days following, were days with temperature below normal at Washington. These days of falling temperature were usually, though not always, accompanied by a rising barometer. The days preceding the center day were days of rising temperature, which was usually well above normal and accompanied by rainfall.

If we assume that long radio waves from Europe reach America by a series of more or less regular reflections between the Kennelly-Heavi-

side layer and the earth, the last reflection from the ionized layer quite probably would occur above a point not far from the Maine coast.

It seemed important, therefore, to obtain some idea of the weather conditions in this region. Average curves were made of temperature changes at Eastport, Maine, and compared with those of Washington. Fig. 6 shows that in the majority of the storms affecting both Washington and Eastport for the whole period 1924 to 1928 the greatest temperature drop in Eastport took place within 24 hours after the greatest drop in Washington. In 1924 and 1926 (Figs. 3 and 4) the drop in Eastport came on an average on the following day.

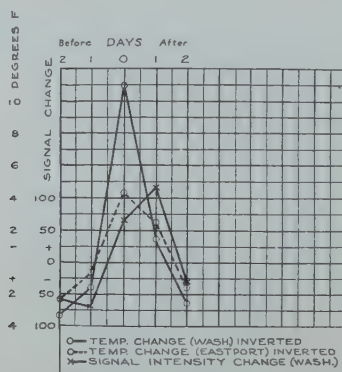


Fig. 6—Average daily percentage change of signal, with the temperature changes at Eastport and Washington, from 1924 to 1928.

In all curves for the individual years (Figs. 3, 4, and 5) the rise in signal strength after the storm is well marked. In most years, too, falling signal intensity occurs as soon as the barometer starts downward and the temperature rises.

Except for 1927 (Fig. 4), the signal strength is rising on the day of the maximum temperature drop at Washington (center day). The rainfall curve for this year reaches a maximum on zero day. This suggests the possibility that increased static which usually accompanies rainstorms may have influenced the observations. This does not seem probable, however, as static is seldom high in the months considered, and in only one curve, that of 1929, does the greatest drop in signal intensity fall on the day of maximum rainfall. There are small variations from the course of the five-year mean (Fig. 6) in the signal intensity curves for 1925 (Fig. 3) and 1927 (Fig. 4), and in the Eastport temperature curves for 1924 and 1926 (Fig. 4). It is interesting to note in connection with these irregularities, that the years 1925, 1926, and 1927 contained the greatest number of magnetically disturbed days (No. 1 and No. 2) for the six years examined.

All the curves show a marked falling-off of signal intensity one or two days before the storm passes Washington. Judging from the pressure and rainfall* curves, this decrease appears to occur in front of the low as it approaches Washington. As soon as the low-pressure center has passed, signal strength increases. For all the years examined the maximum rise falls on the day of, or on the day after, the passing of this center. In four of the years radio intensity begins to decrease as soon as the barometer falls and the temperature rises. For two years, 1927 (Fig. 4) and 1929 (Fig. 5), there is still an upward trend in the signal on the second day after the storm has passed. In 1927 this increase is well marked, and accompanies a continued rise in pressure.

IV. CONCLUSIONS

For long-wave radio transmission between Europe and Washington, D. C., there appears to be a decided drop in signal intensity coincident with heavy rainfall, rising temperature, and falling barometer, at the receiving station at the time of general storms, and an increased signal intensity as the storm center passes and is followed by clear and colder weather. This rise in intensity continues from one to two days. This is sufficient time for a storm to reach and pass Eastport traveling normally to the northeast.

A peculiar indication of this study is the seemingly preponderant effect of weather conditions on signals within a few hundred kilometers of the receiving station at Washington, D. C. in comparison with the influence of the weather over all the rest of the path.

If we accept the existence of a connection between radio wave propagation in the upper atmosphere and storms which occur at the earth's surface, new problems present themselves to the geophysicists, for, as Austin has pointed out in the first paper mentioned, either radio waves are subject to large absorption in the lower atmosphere, due to a degree of ionization not known to exist, or surface storms are influenced by conditions existing at great heights.

Grateful acknowledgement is made to W. J. Humphreys of the U. S. Weather Bureau, whose advice contributed materially to the preparation of the weather data. These data were kindly furnished by the Weather Bureaus at Washington and Atlanta, Georgia.

* Dr. Humphreys has suggested that the state of dryness or wetness of the antenna insulation may have appreciably affected the strength of reception. The radio-frequency resistance of the antenna circuit used at this laboratory is checked regularly. For the past five years except under extremely abnormal conditions such as heavy sleet the variation from the mean antenna resistance (85 ohms) has not exceeded 9 per cent. This would result in approximately a signal strength variation of 10 per cent, which is within the limit of accuracy of the method. The variation in field intensity during the passage of a storm is frequently from 25 to 100 per cent as shown in Fig. 1.

THE GROUNDED CONDENSER ANTENNA RADIATION FORMULA*

By

W. HOWARD WISE

(American Telephone and Telegraph Company, New York City)

Summary—Exact formulas for the wave function and vertical electric field at the surface of the ground are derived for a vertical dipole of zero height.

SOMMERFELD'S derivation of series developments for the wave function of a grounded condenser antenna¹ makes use of approximations based on the assumption that $k_1^2/k_2^2 = 1/(\epsilon + i2c\lambda\sigma)$ is negligibly small in comparison with unity. This was a legitimate assumption for the long wavelengths in use at the time his paper was written. But with a very short wave the conductivity σ and dielectric constant ϵ may be so low that k_1^2/k_2^2 is scarcely negligible in comparison with

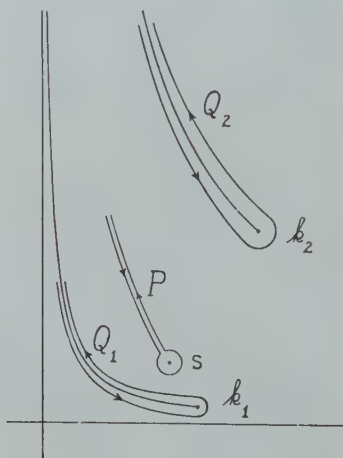


Fig. 1

unity. Under such conditions approximations are a source of worry and one prefers an exact formula. It is therefore of some interest and importance to derive the series without the use of this approximation. The only limitation on the formulas here derived for use at the surface of the ground is that the distance must be large enough for the antenna to look like a dipole.

The electric and magnetic fields of an antenna are obtained by

* Decimal classification: R121. Original manuscript received by the Institute, April 14, 1931.

¹ *Ann. der Phys.*, **28**, 665, 1909.

differentiating the antenna's wave function.² This analysis begins with Sommerfeld's expression for the wave function of a vertical dipole centered on the interface between air and earth, (expression (1) of this paper). Sommerfeld wraps the real axis path of integration around the zero of the denominator and the two branch cuts from k_1 and k_2 to $+i\infty$ and denotes the three wave function components contributed by the resulting three paths of integration by P , Q_1 , and Q_2 , respectively. The component P , which is more or less confined to the region of the interface and therefore known as the ground wave, being merely $2\pi i$ times the residue at the pole, presents no difficulty; it is the components Q_1 and Q_2 , for which series expansions must be produced, that complicate the problem. At sufficient distances from the origin Q_1 and Q_2 are conveniently given by asymptotic expansions, (in this paper, series (8) and (9) respectively). Near the origin Q_1 and Q_2 are inextricably tangled up with P and one must use convergent series expansions for $Q_1 + P/2$ and $Q_2 + P/2$, (in this paper, series (5) and (6), respectively). The component Q_2 being highly attenuated radially $Q_2 + P/2$ is for most practical purposes replaceable by $P/2$.

Sommerfeld replaced m in (1) by $\sqrt{k_1^2 - k_z^2}$ and expanded $1/(l + \tau^2 \sqrt{k_1^2 - k_z^2})$ into a series in $1/l$. The essential novelty in the present contribution is the transformation from (1) to (4). By means of (4) exact series expansions for (1) with $z=0$ are easily obtained.

The wave function of a condenser antenna is, with $\mu=1$,

$$\frac{1 + \tau^2}{2} \int_{-\infty}^{\infty} \frac{1}{l + \tau^2 m} H_0^{(1)}(\lambda r) e^{-z l} \lambda d\lambda \quad (1)$$

$$= \frac{1 + \tau^2}{2} \int_{-\infty}^{\infty} \left(\frac{l}{l^2 - \tau^4 m^2} - \frac{\tau^2 m}{l^2 - \tau^4 m^2} \right) H_0^{(1)}(\lambda r) e^{-z l} \lambda d\lambda \quad (2)$$

$$= \frac{1}{2(1 - \tau^2)} \int_{-\infty}^{\infty} \left(\frac{l}{\lambda^2 - s^2} - \frac{\tau^2 m}{\lambda^2 - s^2} \right) H_0^{(1)}(\lambda r) e^{-z l} \lambda d\lambda \quad (3)$$

$$= \frac{1}{2(1 - \tau^2)} \int_{-\infty}^{\infty} \left(\frac{l}{l^2 + \tau^2 s^2} - \frac{\tau^2 m}{m^2 + \tau^{-2} s^2} \right) H_0^{(1)}(\lambda r) e^{-z l} \lambda d\lambda, \quad (4)$$

where $\tau = k_1 \div k_2$, $s = k_1 \div \sqrt{1 + \tau^2}$, $l^2 = \lambda^2 - k_1^2$, $m^2 = \lambda^2 - k_2^2$ and $k^2 = \epsilon \mu \omega^2 + 4\pi \sigma \mu i \omega$. The subscripts 1 and 2 refer to air and ground respectively.

The second half of (2) contains all the odd ν terms in Sommerfeld's equation (54). Sommerfeld finds that, with some approximation, these odd terms add up to $P/2$. Integrating around the pole at $\lambda=s$ the second half of (3) yields exactly $P/2$, if the sign of $\sqrt{s^2 - k_2^2}$ is negative,

² See H. Bateman, Electrical and Optical Wave-Motion, paragraph 4.

or $-P/2$, if the sign of $\sqrt{s^2 - k_g^2}$ is positive. Integrating around the pole at $\lambda = s$ the first half of (3) yields exactly $P/2$.

The first half of (4) can be written

$$\begin{aligned} & \frac{1}{2(1 - \tau^2)} \int_{-\infty}^{\infty} \left(\frac{1}{l} - \frac{\tau^2 s^2}{l^3} + \frac{\tau^4 s^4}{l^5} - \dots \right) H_0^{(1)}(\lambda r) e^{-z l} \lambda d\lambda \\ &= \frac{1}{1 - \tau^2} (I_1 - \tau^2 s^2 I_3 + \tau^4 s^4 I_5 - \dots) \end{aligned}$$

where,

$$\begin{aligned} I_n &= \frac{1}{2} \int_{-\infty}^{\infty} l^{-n} H_0^{(1)}(\lambda r) e^{-z l} \lambda d\lambda \\ &= \frac{1}{(n-2)!} \int_0^{\infty} \frac{\lambda^{n-2}}{\sqrt{r^2 + (z + \lambda)^2}} e^{i k_1 \sqrt{r^2 + (z + \lambda)^2}} d\lambda \dagger \end{aligned}$$

Assuming that z is zero,

$$\begin{aligned} I_1 &= \frac{e^{i k_1 r}}{r}, \quad I_3 = -\frac{e^{i k_1 r}}{i k_1}, \quad I_5 = \left(1 - \frac{1}{x}\right) \frac{r e^x}{1 \cdot 3 (i k_1)^2}, \\ I_7 &= -\left(1 - \frac{3}{x} + \frac{3}{x^2}\right) \frac{r^2 e^x}{1 \cdot 3 \cdot 5 (i k_1)^3}, \\ I_9 &= \left(1 - \frac{6}{x} + \frac{15}{x^2} - \frac{15}{x^3}\right) \frac{r^3 e^x}{1 \cdot 3 \cdot 5 \cdot 7 (i k_1)^4}, \\ I_{11} &= -\left(1 - \frac{10}{x} + \frac{45}{x^2} - \frac{105}{x^3} + \frac{105}{x^4}\right) \frac{r^4 e^x}{1 \cdot 3 \cdot 5 \cdot 7 \cdot 9 (i k_1)^5}, \dots, \end{aligned}$$

where $x = i k_1 r$. The polynomials progress according to the law $p_n = p_{n-4} - [(n-4)/x] p_{n-2}$.

The first half of (4) thus becomes, with $\tau^2/(1 + \tau^2) = a$,

$$\begin{aligned} & \frac{1}{1 - \tau^2} \left\{ 1 - \frac{ax}{1} + \frac{a^2 x^2}{1 \cdot 3} \left(1 - \frac{1}{x}\right) \right. \\ & \quad \left. - \frac{a^3 x^3}{1 \cdot 3 \cdot 5} \left(1 - \frac{3}{x} + \frac{3}{x^2}\right) + \dots \right\} \frac{e^x}{r} \\ &= \frac{i k_1}{1 - \tau^2} \cdot \frac{e^x}{x} (1 - A_1 x + A_2 x^2 - A_3 x^3 + \dots) \end{aligned} \quad (5)$$

† Sommerfeld, "Über die Ausbreitung der Wellen in der drahtlosen Telegraphie," *Ann. der Phys.*, **28**, 1909, equation (49a).

where,

$$A_1 = a + \frac{a^2}{3} + \frac{a^3}{5} + \frac{a^4}{7} + \cdots = \sqrt{a} \tanh^{-1} \sqrt{a}, \quad A_2 = A_1 - a$$

and

$$A_n = [(2n - 3)A_{n-1} - aA_{n-2}]/(n - 1)^2.$$

When z is zero the second half of (4) is exactly the first half of (4) with k_1 and k_2 interchanged. Hence, by interchanging k_1 and k_2 in (5), the second half of (4) is

$$\begin{aligned} & \frac{-\tau^2}{1-\tau^2} \left\{ 1 - \frac{a_2 x_2}{1} + \frac{a_2^2 x_2^2}{1 \cdot 3} \left(1 - \frac{1}{x_2} \right) \right. \\ & \quad \left. - \frac{a_2^3 x_2^3}{1 \cdot 3 \cdot 5} \left(1 - \frac{1}{x_2} + \frac{3}{x_2^2} \right) + \cdots \right\} \frac{e^{x_2}}{r} \\ &= \frac{-\tau^2}{1-\tau^2} \cdot \frac{e^{x_2}}{r} (1 - B_1 x_2 + B_2 x_2^2 - B_3 x_2^3 + \cdots), \end{aligned} \quad (6)$$

where $a_2 = 1/(1+\tau^2)$, $x_2 = ik_2 r$, $B_1 = \sqrt{a_2} \tanh^{-1} \sqrt{a_2}$, $B_2 = B_1 - a_2$ and $B_n = [(2n-3)B_{n-1} - a_2 B_{n-2}]/(n-1)^2$.

Only the second of the two forms of (6) is suitable for numerical computation.

As an interesting partial check on the correctness of (5) and (6) it is not very hard to evaluate the ambiguities and verify that with $k_1 = k_2 = k$ their sum is e^{ikr}/r .

The differential equation satisfied by (5) is

$$y'' + \frac{1}{x} y' + (a - 1)y = \frac{ik_1}{1-\tau^2} \left(\frac{1}{x^3} - \frac{1}{x^2} \right) e^x. \quad (7)$$

The ascending series solution of (7) is just (5) with A_1 an arbitrary constant. The A_1 terms in (5) sum up, of course, to $-[ik_1/(1-\tau^2)] A_1 J_0(sr)$.

The descending series solution of (7) is

$$\begin{aligned} & -\frac{1}{1-\tau^2} \left\{ \frac{1}{ax} \left(1 - \frac{1}{x} \right) + \frac{1 \cdot 3}{a^2 x^2} \left(1 - \frac{3}{x} + \frac{3}{x^2} \right) + \cdots \right\} \frac{e^x}{r} \\ &= \frac{ik_1}{1-\tau^2} \cdot \frac{e^x}{x} \left(\frac{C_1}{x} + \frac{C_2}{x^2} + \frac{C_3}{x^3} + \cdots \right), \end{aligned} \quad (8)$$

where,

$$C_1 = -\frac{1}{a}, \quad C_2 = -\frac{3}{a^2} + \frac{1}{a} \text{ and}$$

$$C_n = \frac{1}{a} [(2n-1)C_{n-1} - (n-1)^2 C_{n-2}].$$

The series (5) is $Q_1 + P/2$ and $P/2$ decreases exponentially with r . The series (8) is therefore the asymptotic expansion for Q_1 . Hence, by interchanging k_1 and k_2 in (8) the asymptotic expansion for Q_2 is

$$\begin{aligned} & \frac{\tau^2}{1-\tau^2} \left\{ \frac{1}{a_2 x_2} \left(1 - \frac{1}{x_2} \right) + \frac{1 \cdot 3}{a_2^2 x_2^2} \left(1 - \frac{3}{x_2} + \frac{3}{x_2^2} \right) + \dots \right\} \frac{e^{x_2}}{r} \\ &= \frac{ik_1 \tau}{1-\tau^2} \cdot \frac{e^{x_2}}{x_2} \left(\frac{d_1}{x_2} + \frac{d_2}{x_2^2} + \frac{d_3}{x_2^3} + \dots \right), \end{aligned} \quad (9)$$

where,

$$d_1 = \frac{1}{a_2}, \quad d_2 = \frac{3}{a_2^2} - \frac{1}{a_2} \text{ and}$$

$$d_n = \frac{1}{a_2} [(2n-1)d_{n-1} - (n-1)^2 d_{n-2}].$$

As a partial check on the correctness of (8) and (9) it is not very hard to evaluate the ambiguities and verify that with $k_1 = k_2 = k$ their sum is e^{ikr}/r .

The writer first derived the asymptotic expansion (8) for Q_1 by direct manipulation of (5). The series (5) can be expressed in terms of $1-ax + (ax)^2/1 \cdot 3 - (ax)^3/1 \cdot 3 \cdot 5 + \dots$ and its derivatives. Then the relation

$$\begin{aligned} 1 - \frac{y}{1} + \frac{y^2}{1 \cdot 3} - \frac{y^3}{1 \cdot 3 \cdot 5} + \dots &= -i \sqrt{\frac{\pi}{2}} y e^{-y/2} \\ -\frac{1}{y} - \frac{1 \cdot 3}{y^2} - \frac{1 \cdot 3 \cdot 5}{y^3} - \dots & \end{aligned} \quad (10)$$

splits $Q_1 + P/2$ into two kinds of terms, exponential terms and terms in $1/y$. The exponential terms were identified with $P/2$. The terms in $1/y$ gave the series (8).

The vertical electric field due to either (5) or (8) is

$$-i\omega \left(y'' + \frac{1}{x} y' \right) = -i\omega \left[\frac{y}{1+\tau^2} + \frac{ik_1}{1-\tau^2} \left(\frac{1}{x^3} - \frac{1}{x^2} \right) e^x \right]. \quad (11)$$

Since P is a solution of (7) with the right hand side replaced by zero the vertical electric field due to P is

$$-i\omega\left(P'' + \frac{1}{x}P'\right) = -i\omega\frac{P}{1+\tau^2} = i\omega\frac{\pi s\tau}{1-\tau^4}H_0^{(1)}(sr). \quad (12)$$

The vertical electric fields due to (6) and (9) are easiest obtained by interchanging k_1 and k_2 in the vertical electric fields due to (5) and (8) respectively and dividing by τ^2 .

Assuming the conductivity of the air to be zero and the dielectric constant of the air to be unity

$$k_1 = 2\pi/\lambda \text{ and } k_2^2 = k_1^2(\epsilon + i2c\lambda\sigma),$$

where ϵ is the dielectric constant of the ground referred to air as unity, σ is the conductivity of the ground in electromagnetic units, c is the velocity of light in centimeters per second and λ is the wavelength measured in centimeters.



BOOK REVIEWS

The National Physical Laboratory Collected Researches. Vol. XXII, 1930. Published by his Majesty's Stationary Office, London, price £1 net. 417 pp. 10×10 inch paper binding.

This is a group of twenty-one authoritative papers on radio and other electrical subjects, all of which have been published elsewhere. Of the fourteen radio papers, one is by Colebrook on receiving antennas, four by Wilmotte, and one by Wilmotte and McPetrie on transmitting antennas and beam systems, one by Thomas on amplifiers, one on radio-frequency current transformers, and one on condenser resistance by Dye, one on high-frequency resistance and one on condenser losses by Wilmotte, one on electron-tube circuit measurements by Hartshorn, one on quartz resonators and one on quartz oscillators by Vigoureux. Of the nonradio papers one was written by Rayner, two by Arnold, two by Melson and Booth, and one by Melson and Baer.

It is a great convenience to have this group of papers in a single volume.

*S. S. KIRBY

* Bureau of Standards, Washington, D. C.

Handbook of Technical Instruction for Wireless Telegraphists. Fourth edition, by H. M. Dowsett. Published from the offices of The Wireless World, Iliffe and Sons, Lt., London. 487 pp., 459 figures. Price, 25 shillings net.

The "Handbook of Technical Instruction for Wireless Telegraphists" provides instruction for seagoing operators and others in the general principles and practice of radio telegraphy, and is illustrated by marine apparatus developed by the radio companies of Great Britain. The handbook also provides a good theoretical course for operators. The theoretical work, while elementary, is especially well done and complete for an operator's handbook. Transmitting and receiving equipment of British manufacture is described in detail. Besides the work on general transmitting and receiving sets there are chapters on direction finding, auto alarm, life boat, and emergency outfits.

*S. S. KIRBY

* Bureau of Standards, Washington, D. C.

Practical Testing Systems, by John F. Rider. Published by Radio Treatise Co., Inc., 1440 Broadway, New York. 147 pp., 99 figures. Price \$1.15.

This book presents a number of practical testing systems suitable for application in connection with radio equipment, principally receiving sets and associated apparatus. The apparatus and methods described are comparatively simple and easy to follow. The contents include sections on measuring instruments, resistance units, oscillators, tube testers, vacuum tube voltmeters, capacity tests, inductance tests, audio and output systems. Seventy-five tests, measurements and pieces of test apparatus are described. Directions for constructing the apparatus are given as well as the methods of testing.

*S. S. KIRBY

* Bureau of Standards, Washington, D. C.

BOOKLETS, CATALOGUES, AND PAMPHLETS RECEIVED

Copies of the publications listed on this page may be obtained gratis by addressing a request to the manufacturer or publisher.

A 12-page folder of mimeographed material issued by the Weston Electrical Corporation of Newark, N. J., describes their Model 590 modulated radio-frequency oscillator. The oscillator is completely shielded and has a continuously variable frequency range from approximately 115 kc to 200 kc for testing intermediate frequency amplifiers, and a second range from 550 kc to 1500 kc covering the broadcast spectrum. A mimeographed folder of about 20 pages entitled "Service Manual and Instructions for Weston Model 556 Type 3 Radio Set Tester" contains test data for the use of those servicing radio receivers. "Rectifier Type Instruments," especially those of the Model 301 class, are described in a leaflet by this title. An instrument for determining percentage modulation in systems using the constant current system of modulation is described in data sheets entitled "Model 588 Modulation Meter."

Engineering data sheets and technical bulletins covering various individual tubes in the CeCo line are available in a convenient folder from the CeCo Manufacturing Company, Inc., Providence, R. I.

Bulletin No. 9 gives data on several new types of resistors manufactured by the Ohmite Manufacturing Co., 636 N. Albany Ave., Chicago. Stock list No. 8 lists a more complete line of resistors manufactured by this concern.

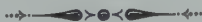
The De Forest Radio Co. of Passaic, N. J., has recently issued a book giving "A Quarter Century of Radio Progress," a folder on "Transmission Audions," and a new price list.

Bulletin 700 of the Shallcross Manufacturing Company, Collingdale, Pa. is devoted to "Kilovoltmeter Multipliers" for low current meters. Bulletin 900 describes "Shallcross Megohm Decade Resistance Boxes." These boxes are available with a resistance of 60 megohms in steps of 1 megohm. The accuracy of calibration is 0.1 per cent.

Bulletins 3001 and 3002 are devoted to portable amplifying and pick-up equipment manufactured by the Radio Receptor Company, Inc., 106 Seventh Ave., New York.

Three booklets have recently been issued by the Stenode Corporation of America, Hempstead Gardens, L. I., N. Y. One of these, "The Stenode," is a paper delivered by Dr. James Robinson before the Radio Club of America. "Engineering Bulletin Number One" is a 23-page booklet giving a general outline of the stenode system, while "Quartz Crystals in Radio Receiving Circuits" deals with the use of quartz resonators in superheterodyne receivers.

Heavy duty rheostats and potentiometers manufactured by the De-Jur-Amsco Corporation, 95 Morton St., New York, N. Y. are described in a folder recently issued by this firm.



REFERENCES TO CURRENT RADIO LITERATURE

THIS is a montly list of references prepared by the Bureau of Standards, and is intended to cover the more important papers of interest to the professional radio engineer which have recently appeared in periodicals, books, etc. The number at the left of each reference classifies the reference by subject, in accordance with the "Classification of radio subjects: An extension of the Dewey Decimal System," Bureau of Standards Circular No. 385, which appeared in full on pp. 1433-56 of the August, 1930, issue of the PROCEEDINGS of the Institute of Radio Engineers. The classification numbers are in some instances different from those used in the earlier version of this system used in the issues of the PROCEEDINGS of the Institute of Radio Engineers before the October 1930, issue.

The articles listed are not obtainable from the Government or the Institute of Radio Engineers, except when publications thereof. The various periodicals can be secured from their publishers and can be consulted at large public libraries.

R100. RADIO PRINCIPLES

- R111.2 Boll, M. Considérations électroniques sur l'émission radioélectrique (Electronic considerations of radiation). *L'Onde Électrique*, 10, 251-258; June, 1931.

The classical concept of the doublet may be advantageously replaced by the idea of an oscillating electron. It permits the calculation of the electric and magnetic fields at all distances from the radiator as well as the radiating resistance of the latter.

- R113 Anderson, C. N. Notes on radio transmission. *PROC. I.R.E.*, 19, 1150-1165; July, 1931.

Considerable data on radio transmission have been obtained the past few years in connection with the establishment and operation of various radio-telephone services by the Bell System. It is the purpose of these notes to present certain aspects of some of these data which may be of interest in the development of a general physical picture of radio transmission and in indicating the effects of disturbances accompanying storms in the earth's magnetic field.

- R113.5 Pickard, G. W. A note on the relation of meteor showers and radio reception. *Proc. I.R.E.*, 19, 1166-1170; July, 1931.

A comparison of reception measurements with meteor showers over five-year periods indicates an accompanying increase of night fields and a decrease of day fields. The highest correlation appeared between monthly means of meteor hour rates and night fields. No associated disturbance of terrestrial magnetism was found.

- R113.62 Goubon, G. and Zenneck, J. Messungen von Echos bei der Ausbreitung elektromagnetischer Wellen in der Atmosphäre (Echo measurements of electromagnetic waves in the atmosphere). *Zeits. für Hochfrequenz.*, 37, 207-218; June, 1931.

Results of echo measurements taken over the period September, 1929, to July, 1930, are reported. Salient features of the procedure employed include the strictly electrical method of producing the jab impulses for modulating the radio transmitter, the photographic recording of Braun tube figures at the receiving end and the method of evaluating these figures.

- R125 Gothe, A. Neuere Messungen an Kurzwellen-Richtantennen (Recent measurements on short-wave directional antennas). *Elek. Zeits.*, 52, 872-875; July, 1931.

The directional characteristics of short-wave antenna arrays for transmission and reception were measured at close range. Effective signal increase and signal-to-noise ratio were measured over transatlantic distances. In every case experimental results were shown to check with theoretical calculations.

- R125 Sterba, E. J. Theoretical and practical aspects of directional transmitting systems. *PROC. I.R.E.*, 19, 1184-1215; July, 1931.

Some of the more important principles involved in the development of directional transmitting antennas at present employed by the Bell System are discussed. Various practical problems are described, including antenna tuning procedure, transmission line adjustments, and sleet melting facilities.

- R131 Valves—The Eta series. *Wireless World and Radio Review*, 28, 657-660; June, 1931.

Data and characteristic curves of a representative series of British vacuum tubes are given.

- R132 Barton, L. E. High audio power from relatively small tubes. *PROC. I.R.E.*, 19, 1131-1149; July, 1931.

A method of obtaining audio outputs five to ten times the usual output of a tube of given size is presented. This is accomplished with the same plate voltage, lower average plate dissipation and with no serious effects on the tube, by taking advantage of essential features of the class "B" amplifier.

- R133 Benioff, H. The operating frequency of regenerative oscillatory systems. *PROC. I.R.E.*, 19, 1274-1277; July, 1931.

The operating frequency of regenerative oscillatory systems is quantitatively derived in terms of the natural frequency, the damping constant, and the phase of the driving force. As an example the results are used to calculate the change in rate of a pendulum clock due to a given variation in the phase of the driving impulses. Applications to other types of systems are briefly indicated.

- R134 Arenberg, A. Systèmes polyphasés à auto-excitation (Self-excited polyphase systems). *L'Onde Électrique*, 10, 259-274; June, 1931.

It is shown that several ordinary vacuum-tube oscillators may be combined to produce polyphase currents. The fundamental frequency does not circulate in the power supply wires of the combination but these circuits carry currents of $f=q, n, \omega$ where ω =fundamental frequency; n =number of phases; $q=1, 2, 3, \dots$. A number of applications are discussed.

- R134 Nelson, J. R. High level automatic or self bias detection. *Electronics*, 3, 14-15; July, 1931.

The principles of self or automatic bias detection as used extensively in present day radio receivers are explained.

- R141
×R382.1 Nelson, J. R. Note on radio-frequency transformer coupled circuit theory. *PROC. I.R.E.*, 19, 1233-1241; July, 1931; discussion, 1281-1282; July, 1931.

Equations considering the effects of output and distributed capacities and primary resistance are developed for radio-frequency transformer-coupled amplifiers using either a tuned or an untuned primary. It is shown that the amplification obtainable with a tube and a transformer having an untuned primary may be made nearly uniform over a frequency range such as that covered by the broadcast band by adding resistance to the primary to reduce the high-frequency amplification.

- R141.2 Langly, R. H. Tuning by permeability variation. *Electronics*, 3, 8-10; July, 1931.

A new method of tuning radio-frequency circuits is described. The variable air condenser is eliminated and tuning is accomplished by gradually inserting specially prepared iron cores into the radio-frequency transformers. Constant amplification and selectivity over the broadcast band, as well as economic advantages are claimed.

- R142.3
×R382.1 Reed, M. The design of high-frequency transformers. *Experimental Wireless and the Wireless Engineer*, 8, 349-355; July, 1931.

An analysis of the factors which influence the design of high-frequency transformers is given. It is pointed out that the same considerations govern the design of both interstage and antenna coupling transformers.

- R142.3 Barclay, W. A. Making the most of the low-frequency transformer.
 ×R382.1 *Wireless World and Radio Review*, 29, 30-33; July, 1931; 72-74; July, 1931.

Simplified calculations using alignment charts are suggested for selecting the proper tube and correct turns ratio for the low-frequency transformer-coupled stage.

- R142.5 van B. Roberts, W. Capacity-coupled circuits. *Electronics*, 3, 20; July, 1931.

An analysis of capacity-coupled circuits with a view of obtaining maximum amplification.

- R142.5 Barclay, W. A. The variation of magnification with pitch in re-
 ×R363.2 sistance-capacity coupled amplifiers. *Experimental Wireless and the Wireless Engineer*, 8, 362-369; July, 1931.

A purely-theoretical analysis of the frequency characteristics of resistance-capacity coupled amplifiers.

- R191 Boella, M. Performance of piezo-oscillators and the influence of the
 ×537.65 decrement of quartz on the frequency oscillations. *Proc. I.R.E.*, 19, 1252-1273; July, 1931.

The performance of piezo oscillators is treated on the basis of experimentally determined resonance curves of the quartz and with the help of vector diagrams. The influence of the decrement of the quartz resonator on the oscillation frequency is examined. This study has led to the development of an arrangement which permits the quartz to oscillate in proximity to its frequency of resonance and to reduce thereby the influence of the decrement on frequency to about 1/10 of that usually found.

R200. RADIO MEASUREMENTS AND STANDARDIZATION

- R210 Schäffer, W. and Lubszynski, G. Measuring frequency characteris-
 ×535.38 tics with the photo-audio generator. *Proc. I.R.E.*, 19, 1242-1251;
 ×R350 July, 1931; *Elek. Nach. Technik*, 8, 213-217; May, 1931.

An audio-frequency generator for frequency measurements is described. Greater simplicity, better wave form and continuous frequency range are some of the advantages claimed over the conventional vacuum-tube generator.

- R210 Nancarrow, F. E. Frequency measurement in the British Post
 Office. *The Post Office Electrical Engineers' Journal* (London), 24,
 155-159; July, 1931.

The tuning fork frequency standard of the British Post Office is described as well as methods used in comparing and measuring low, medium, and high frequencies.

- R212 Whitehead, C. Calibrating ultra-short wave receivers employing
 super-regeneration. *Experimental Wireless and the Wireless Engi-
 neer*, 8, 370-371; July, 1931.

A Lecher-wire system of suitable dimensions is coupled to the oscillating detector circuit and a meter is connected in the output of the receiving set to indicate the position of successive nodes which are located by means of a short-circuiting bridge, at intervals of $\lambda/2$ along the length of the Lecher system.

- R214 Brown, S. L. and Harris, S. Measurement of temperature coefficient
 and pressure coefficient of quartz-crystal oscillators. *Review of
 Scientific Instruments*, 2, 180-183; March, 1931.

A method of measurement is used whereby variation in frequency of a high-frequency oscillator can be measured to a fraction of a part in a million. The temperature effect is of the order of 20 parts per million per degree C while the pressure effect is of the order of 6 parts per million per atmosphere.

- R223 Goodlet, B. L.; Edwards, F. S.; and Perry, F. R. Dielectric phenomena at high voltages. *Jour. I.E.E.* (London), **69**, 695-738; June, 1931.
Discusses the breakdown of air, oil, and solid dielectrics by normal, impulsive, and high frequency voltages. A large amount of original numerical data is given, covering the entire range of voltages up to 1 million volts.
- R240 Frühauf, H. Die Messung des Dämpfungswiderstandes von Hochfrequenzschwingungskreisen mit Hilfe der Dynatronschaltung (Measuring the damping resistance of high-frequency oscillatory circuits by means of the dynatron). *Zeit. für Hochfrequenz.*, **37**, 229-234; June, 1931.
The use of the dynatron principle in measuring the damping resistance of oscillatory circuits is outlined. Several other practical measurements that may be accomplished with the dynatron circuit are mentioned.
- R242.12 Colebrook, F. M. Thermo-junctions at high radio frequencies. *Experimental Wireless and the Wireless Engineer*, **8**, 356-361; July, 1931.
An investigation of mutual consistency of thermojunction milliammeters was made by comparing them with a special vacuum-tube milliammeter over the frequency range of 0 to 10^7 cycles/second. The maximum mutual error was about 5 per cent and most of the variation occurred over the range 10^6 to 10^7 cycles per second.
- R261 Smith-Rose, R. L. Testing wireless receivers. *Wireless World and Radio Review*, **28**, 636-638 and 653-655; June, 1931.
Standardized tests of broadcast radio receivers are suggested for England.
- R265.2 Olney, B. Notes on loud speaker response measurements and some typical response curves. *PROC. I.R.E.*, **19**, 1113-1129; July, 1931.
The difficulties in loud speaker measurements are briefly reviewed and a description of the acoustic features of both indoor and outdoor measuring systems are given. The interpretation of loud speaker response curves is discussed.
- R270 Field strength measurements of short-wave transmissions. *Marconi Review*, No. 30, 1-12. May-June, 1931.
An analysis of the results of a series of systematic measurements of short-wave signal intensities made at the Marconi Research Laboratories at Chelmsford over the period October, 1930, to January, 1931.
- R281 Barringer, L. E. Mycalex—A molding material with unique properties. *General Electric Review*, **34**, 406-409; July, 1931.
The unique properties of mycalex are enumerated and a table of comparative properties of mycalex, wet-process porcelain, and transparent fused-quartz is given.
- R300. RADIO APPARATUS AND EQUIPMENT
- R320 Hatry, L. W. Anti-noise receiving aerials. *Modern Radio*, **1**, 7-11; July, 1931.
Proved methods of eliminating man-made electrical interference from receiving antennas are described.
- R333 Tubes for generating eighteen-centimeter waves. *Electronics*, **3**, 4; X R355.5 July, 1931.
A brief description of the characteristics and construction of the vacuum tube used in the recent radio telephone experiments using wave-lengths of the order of eighteen centimeters.
- R339 Reich, H. J. A periodic contactor operated by a neon-tube oscillator. *Review of Scientific Instruments*, **2**, 164-170; March, 1931; 234-236; April, 1931.

A simple device, capable of closing a circuit periodically at any desired frequency and holding it closed for any desired fraction of a cycle is described.

- R355.4 Telephone transmitting equipment on board the "Homer." *Marconi Review*, No. 30, 23-28; May-June, 1931.

A description is given of the short-wave telephone transmitters recently installed on the "Homer" and "Empress of Britain." These transmitters are similar to that originally designed for use on Marconi's yacht, the "Elettra" and equipment of similar design is now being employed on the Rome-Sardinia duplex circuit operating at $\lambda = 9.87$ meters and $\lambda = 9.77$ meters.

- R355.5 Developments in the use of very short radio waves. *The Post Office Electrical Engineers' Journal* (London), 24, 152-154; July 1931.

The equipment used for ultra-high-frequency ($\lambda = 18$ cm) telephony across the English Channel is briefly described.

- R355.6 Dixon, E. J. C. Frequency control equipment of Post Office short-wave transmitters. *The Post Office Electrical Engineers' Journal* (London), 24, 159-164; July, 1931.

Piezo-electric frequency control equipment used by the British Post Office is described in detail.

- R355.9 David, P. Générateur de F. E. M. étalonnées sur ondes courtes (A generator of standard e.m.f.'s at high frequencies). *L'Onde Electrique*, 10, 233-250; June, 1931.

A type of standard generator is described. It furnishes known e.m.f.'s from one microvolt to one volt at wave lengths from 10 to 100 meters with a precision of the order of 5 per cent.

- R390 Dinsdale, A. Remote tuning control systems. *Wireless World and Radio Review*, 28, 646-650; June, 1931.

Three devices for remote tuning control are described. All three employ synchronous motors and are marketed by American concerns.

R400. RADIO COMMUNICATION SYSTEMS

- R412 Cowan, F. A. Overseas radio telephone service. *Electrical Engineering*, 50, 476-477; July, 1931.

A brief account of some of the more recent developments in radio telephone systems between North American and other countries.

- R423.4 Whiting, H. G. Der Kurzwellen-Fernsprechsender in Rugby. (The short-wave radio telephone transmitter at Rugby). *Elek. Zeits.*, 52, 895-898; July, 1931.

A detailed semitechnical description of the transatlantic radio telephone transmitter at Rugby is given.

R500. APPLICATIONS OF RADIO

- R521.1 Hinman, W. S., Jr. Automatic volume control for aircraft radio receivers. *Bureau of Standards Journal of Research*, 7, 37-46; July, 1931. Bureau of Standards Research Paper No. 330.

An automatic volume-control device is described for use primarily in the reception of visual type radio range beacon signals, the device being easily applied to existing aircraft radio receiving sets. This device operates on the output voltage of the radio receiver, and is provided with a filter unit to prevent operation of the automatic volume control by signals other than those from the range-beacon. The controlling voltage is derived from the output of the radio receiver, part of which is rectified and then applied as negative bias to the radio-frequency amplifier. The automatic volume control maintains a substantially constant output voltage for input voltage variations of the order of 5000 to 1. A distance indicator, operating in conjunction with the automatic volume-control device, is provided to serve as a gauge of distance from the transmitting station.

- R525 Eisner, F.; Sudeck, G.; Schröer, R.; and Zinke, O. Ver grösserung der effektiven Höhe von Flugzeugschleppantennen (Increasing the effective height of airplane trailing-wire antennas). *Zeits. für Hochfrequenz.*, **37**, 211-229; June, 1931.

The conventional trailing-wire antenna was found to be a poor radiator when compared with the newly developed L-type trailing wire. Comparative experimental results are reported.

- R526.12 Dunmore, F. W. A course indicator of pointer type for the visual radio range-beacon system. *Bureau of Standards Journal of Research*, **7**, 147-170; July, 1931. Bureau of Standards Research Paper No. 336.

A form of tuned-reed radio range beacon course indicator called a reed converter is described, in which the course indications are not given by observing the two reed motions as heretofore, but by means of a zero-center pointer type indicating instrument. The motion of the two reeds generates small alternating voltages, which when rectified by oxide rectifiers and passed in opposing polarities through the zero-center indicating instrument, serve to give course indications by the deflection of the indicating instrument needle in the direction of deviation of the airplane from the course.

- R526.12 Davies, G. L. Theory of design and calibration of vibrating-reed indicators for radio range-beacons. *Bureau of Standards Journal of Research*, **7**, 195-213; July, 1931. Bureau of Standards Research Paper No. 338.

This paper gives a general treatment of the theory of design of vibrating-reed indicators, which was developed in connection with measurement and design work on the tuned-reed course indicator for the aircraft radio range beacon. The equations and conclusions may be readily adapted to apply to any similar vibrating system.

- R580 Marconi portable picture apparatus. *Marconi Review*, No. 30; 13-22; May-June, 1931.

The Marconi portable transmitting and receiving apparatus has been designed to provide means of a semi-portable nature, to enable rough sketches, maps, weather charts, and the like to be transmitted by wireless from the air to ground or between two ground stations.

- R590 Tracing balloon drift by wireless—Super midget radio transmitter. *Wireless World and Radio Review*, **28**, 603; June, 1931; *Electronics*, **3**, 21; July, 1931.

A miniature one-pound radio transmitter attached to meteorological balloons makes it possible to trace the latter by means of radio direction finders.

R800. NONRADIO SUBJECTS

- 347.7 Prindle, E. J. Single Patent Appeal Court is proposed. *Electrical Engineering*, **5**, 502-506; Section 1; July, 1931.

Outlines the foundation for a proposed single U. S. Court of Patent Appeals which would be second only to the U. S. Supreme Court and would abolish the duplicate and conflicting efforts of the ten district courts in patent matters. Full text of the proposed House of Representatives bill is given.

- 535.38 Ruff, H. R. The photo cell. *Wireless World and Radio Review*, **29**, 2-4; 39-42; July, 1931.

The principles and properties of photo-electric cells are explained and some of the manifold applications of such cells are enumerated.

- 535.38 Gray, T. S. A photo-electric integrator. *Journal of the Franklin Institute*, **212**, 77-102; July, 1931.

×510

A machine for the purpose of facilitating mathematical solution of problems requiring the evaluation of an integral, in which the integrand involves a variable parameter is described. It involves the use of an optical system in which the transmission of light is limited in a definite manner by apertures having the shape of the area under curves representing mathematical functions.

- 535.38 Zworykin, V. K. Photocell theory and practice. *Journal of the Franklin Institute*, 212, 1-41; July, 1931.
A comprehensive treatment of photo-electric cells, including history, methods of preparation, and applications. Sound-picture and television systems are described in detail and other applications such as contactless relays and reading aids for the blind are mentioned.
- 535.38 Davies, L. J. Photo cells and thyratrons. *Electrician* (London),
×R339 106, 936-938; June, 1931.
The characteristics of typical photocells and thyratrons are tabulated and discussed. Some of the manifold applications of these electronic devices are enumerated.
- 535.38 Wyeth, C. A. Photo-tube circuit design for sound pictures. *Elec-*
×621.385.96 *tronics*, 3, 22-23; July, 1931.
The potassium caesium, selenium, and photolytic types of photo-tube are described and their suitability for use with various possible circuit arrangements in sound-picture reproduction is discussed.
- 538.11 Ide, J. M. Measurements on magnetostriction vibrators. *PROC. I.R.E.*, 19, 1216-1232; July, 1931.
The study of electromechanical vibrating systems through the measurement of motional impedance was undertaken. The effect of polarizing field, diameter of rod, heat treatment, alternating field, and inductance of exciting coil, on the vibratory characteristics of magnetostrictive resonators are discussed.
- 538.11 Esau, A. Über den Quereffekt der Magnetostraktion (On the transverse effect of magnetostriction). *Physikalische Zeit.* 32, 483-485; June 15, 1931.
The transverse effect is derived mathematically from observed longitudinal and volume effects and is to be compared with direct measurements that are in progress.
- 621.313.23 Mirick, C. B. and Wilkie, H. Temperature rating of engine driven aircraft radio generators. *PROC. I.R.E.*, 19, 1175-1183; July, 1931.
Previously described methods of temperature measurement and computation are applied to engine driven aircraft radio generators in flight. Observed and computed heating curves are shown from which an emission constant for this type of machine has been derived.
- 621.375.1 Raven-Hart, R. Electronic musical instruments. *Electronics*, 3, 18-19; July, 1931.
A résumé of recent European developments in electronic musical devices and a description of some of these instruments that were on display at the International Electronic Music Congress in Munich.



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